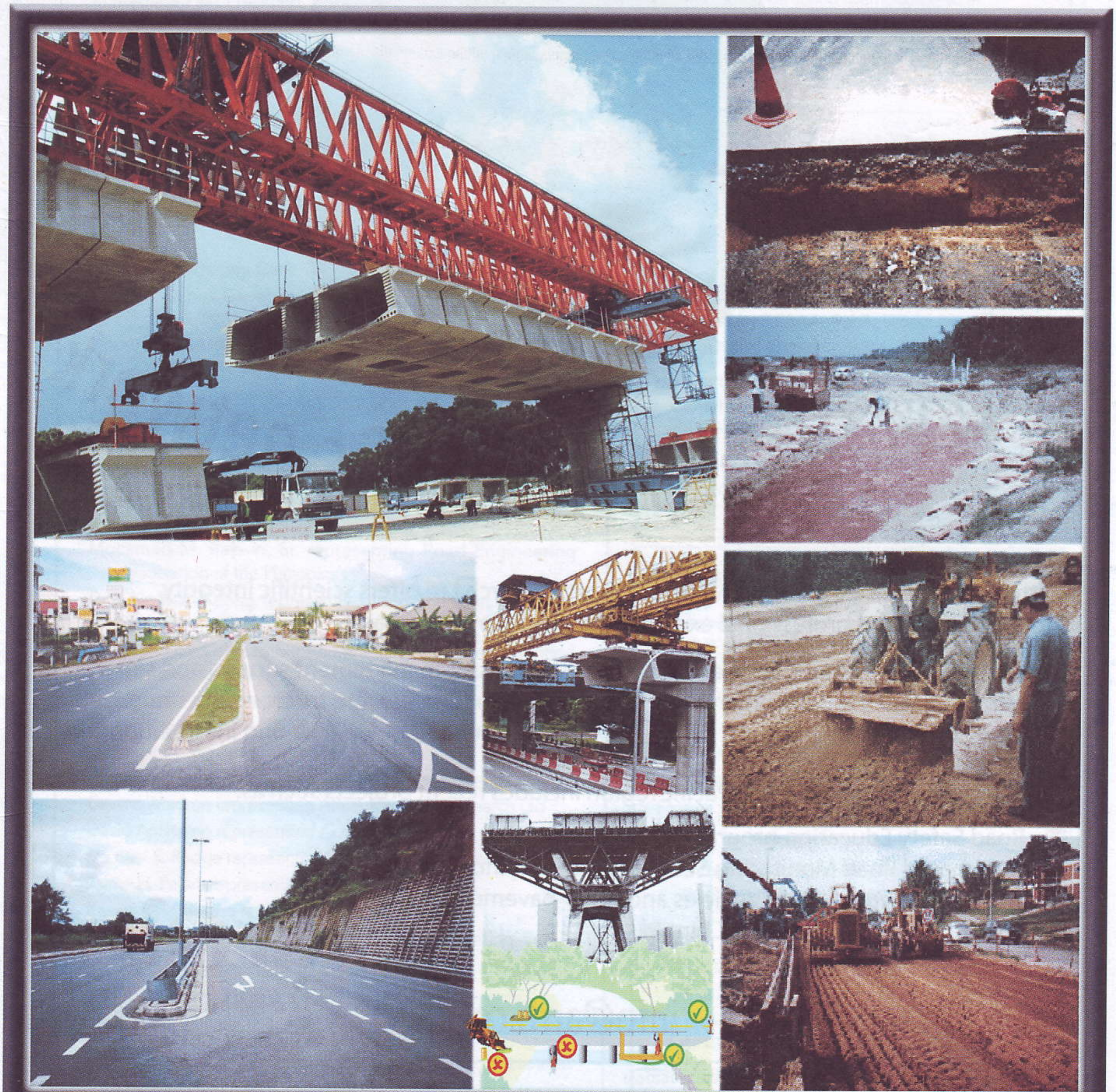
ROAD ENGINEERING ASSOCIATION OF ASIA & AUSTRALASIA

JOURNAL

ISSN: 1394 - 1054

PP7021/8/2003



VOL.10 NO.1

JOURNAL

THE GOVERNING COUNCIL

CONTENTS

JOURNAL

Publisher
– THE ROAD ENGINEERING ASSOCIATION OF ASIA & AUSTRALASIA
No. 46B Jalan Bola Tampar 13/14,
Section 13, 40100 Shah Alam,
Selangor, Malaysia

Tel: 60-3-5513 6380
Fax: 60-3-5513 6390
E-mail: reaaa@po.jaring.my
Website: www.reaaa.com

Printer
– Akitiara Corporation Sdn Bhd
1 & 3, Jalan TPP 1/3,
Taman Industri Puchong,
47100 Puchong,
Selangor D.E.

Lay-Out
– Scanprint Creative Sdn. Bhd.
Tel: 603-7983 6787

ROAD ENGINEERING ASSOCIATION OF ASIA & AUSTRALASIA

Reg. No: 1377 (Selangor)

One of the major objectives of REAAA is technology transfer, ensuring the results of new research and investigations are disseminated to members so that the benefits can be realised with minimum delay. The Road Engineering Association of Asia and Australia Journal aims to publish original work which assists in bringing new knowledge and insights to practitioners and decision-makers.

At its recent meeting in Hanoi, the REAAA Governing Council endorsed the recommendation of the Technical Committee that an Editorial Panel be created whose tasks will be to encourage members in their region to submit technical papers, and other suitable material, for publication in the Joumal, to assist in the reviewing process and to act as a conduit for the collation of other suitable material for publication.

The Editorial Panel seeks to publish material in several categories:

Refereed Papers - Technical papers reporting the results of recent research and development. Manuscripts will be judged on their scholarly merit and relevance to the Journal's readership, initially by the Editorial Panel and then by at least two independent experts in the relevant field. Papers will also be subjected to editorial review to maintain style, consistency and clarity of English expression prior to publication.

Manuscripts submitted for consideration must conform to the following basic requirements:

- ❑ Typed double-spaced on one side of the paper.
- ❑ References cited using the Harvard (author, date) system, with the references listed in alphabetical order at the end of the paper.
- ❑ All tables and copies of figures (including photographs), numbered sequentially in arabic numerals and with full captions, sources and notes, must be placed at the end of the paper, with the position of each table and figure clearly indicated in the text. Originals of illustrations need not be sent until requested by the Editor, and must then be in a form suitable for publication.
- ❑ A face sheet is required, containing the following: Paper title, name(s) and affiliation(s) of the author(s), full contact details (including fax number and e-mail address of the corresponding author) and an abstract of 150-200 words.
- ❑ Papers for review should be sent by e-mail, but should be followed by a faxed copy so that we can check equations, tables, etc.

Incomplete manuscripts not conforming to these requirements, or clearly requiring extensive editing, cannot be accepted for refereeing. Authors not having English as a first language are advised to seek advice from an appropriate reviewer before submitting their paper.

It is the authors' responsibility to guarantee the authenticity of their papers and articles and to obtain the necessary permission and authorisations for material and photographs. The Editor is not responsible for the opinions expressed by the contributors.

Unless notified by the author to the contrary, it will be assumed by the Editor that a submitted paper has not been published or offered elsewhere, and that the author holds full rights of publication. Papers previously published in a refereed journal or published conference proceedings will not normally be accepted (but see 'Invited Papers').

Highly technical papers better suited to a limited audience through specialist academic journals are not encouraged. Essential technical and mathematical material should be included as an appendix rather than break the flow of the paper.

Manuscripts are judged on their scholarly merit and relevance to the Journal's readership, initially by the Editorial Panel and then by at least two independent experts in the relevant field. Papers are also subjected to technical refereeing to maintain style consistency before publication.

Invited Papers - Papers previously presented at Conferences but not formally published, or otherwise not likely to receive widespread attention, may be considered for publication as 'Invited Papers' if they meet

the Journal's purpose and general requirements for publication. These are not normally refereed, but may be edited in consultation with the author. The Editorial Panel welcomes suggestions from readers and Conference organisers about papers that may be suitable, and invites authors to submit their own papers. Details of previous presentation should be made clear. examples of 'invited papers' are those produced in this issue of the Journal.

Technical Notes - technical Notes provide an opportunity for the dissemination of technical ideas, notes on processes, interim findings, and so on, which are not sufficiently developed or complete to warrant a full paper. the suggested maximum length is 1500 words. Technical Notes are not refereed but may be edited.

Opinion and Letters - Letters to the Editor which present a point of view on material previously published in the Journal, or on a matter of topical interest, are welcome.

Bulletin Board - Brief (100-750 word) and newsworthy items concerning recent project findings, events, innovations, personnel movements etc., with illustrations where appropriate, are welcome.

Reviews and New Publications - Publishers are invited to submit copies of new publications for review and/or announcement. Reviews from readers are welcome.

Conferences - Details of forthcoming events in the region should be forwarded to the Editor. Allow for the fact that the Journal is published twice a year. Reports and commentaries on recent conferences are also invited.

Submissions - All material for publication should be sent to the Editorial Assistant, ARRB Transport Research Ltd, 500 Burwood Highway, Vermont South, Victoria, Australia 3133 or by e-mail to: journal@arrb.com.au.. Papers may also be sent to the local member of the Editorial Panel, who will pass on the material to ARRB on your behalf.

Guidelines for the format of technical papers are provided in an attachment to this edition of the Journal. The preferred format of the paper is electronic, either via e-mail or mailed CD.

Editorial Panel - The members of the Editorial Panel are as follows:

Kieran Sharp
Chairman, REAAA Technical Committee

Evolution of Bridge, Flyover and Viaduct Construction Methodologies in Urbanised Singapore

Lim Chong Teik
Lim Ee Lee
Yap Boon Leong
Yap Cheng Chwee
Land Transport Authority, Singapore

ABSTRACT

Over the years, road infrastructure development in Singapore has seen rapid growth and revolutionary changes to meet ever-increasing demand and higher expectations of road users. To manage such demands and expectations in urbanised and land scarce Singapore, the Land Transport Authority of Singapore (LTA) is faced with a daunting task of enhancing the road network with minimum land take. With these constraints, the LTA is mindful in keeping upgrading projects within the existing traffic corridor such as the conversion of existing at-grade junctions into 2 to 4-tier interchanges, construction of elevated roads and viaducts above existing carriageways and construction of underground tunnel expressways. This paper looks into the evolution of construction methodologies for road development projects in Singapore. The pioneering road projects in the use of segmental concrete construction are also highlighted. This paper also discusses the LTA's experience in facing the challenges that accompany the construction of bridges, flyovers and viaducts in a heavily built-up environment.

1. INTRODUCTION

1.1 The Role of LTA in Road Development in Singapore

The Singapore Government formed the Land Transport Authority (LTA) on 1st September 1995 to spearhead improvements to the land transport system. The LTA has set out a vision to provide Singapore with a world class land transport system and its mission is - "To provide a quality, integrated and efficient land transport system which meets the needs and expectations of Singaporeans, supports economic and environmental goals, and provides value for money."

The 1996 White Paper set out how the LTA intends to achieve its mission, its transport vision for Singapore, its operating philosophy and the initiatives it will take in the short and long term. Over the last 15 to 20 years, the demand for transport had been explosive as the Singaporean society became more mobile and physically dispersed. The number of vehicular trips grew annually by 7%, from 2.7 million trips in 1981 to more than 7 million trips a day now. It is expected to grow to 10 million trips per day by 2010.

Building an efficient road network is an integral part of the LTA's mission. The road network must be comprehensive to sustain economic activity and provide good connectivity to various parts of Singapore. In 1996, roads already constituted 12% of the total land area. This is similar to the land take for housing in Singapore and will gradually continue to increase.

To manage both economic demands and public expectations in urbanised and land scarce Singapore, the LTA is faced with a daunting task of enhancing the road network with minimum land take. With these constraints, the LTA is mindful in keeping upgrading projects within the existing traffic corridor such as the conversion of existing at-grade junctions into 2 to 4-tier interchanges. Also, road development projects have since taken a new meaning with the introduction of bridges, flyovers, elevated roads and viaducts above existing carriageways and underground tunnel expressway to increase road space without substantially increasing land take.

2. OBJECTIVES OF PAPER

This paper addresses LTA's approach in improving existing road network through the various bridge, flyover and viaduct options and their construction methods. This paper also provides a history of the different construction methods from 1950s until present day. It also discusses the LTA's experience in facing the challenges that accompany the infrastructure development through some of the projects, which are presented in this paper.

2.1 Challenges Faced By LTA For Road Development In An Urbanised Environment

In Singapore, road development projects are almost always required at locations where the areas are already heavily built-up - both above and below ground. The various challenges are highlighted below:

2.1.1 Evolving the Best Design

The implementation of all road development projects requires careful planning and design. In the selection of the routing details, various factors have to be taken into account e.g. the existing land uses, the existing road system, planning commitments, land take, estimated construction cost, existing traffic flows and characteristics, bus routes and the route and location of large underground utility services, just to mention a few. Alternative designs are evolved using our road design software and appraised before the best design is selected for detailed development and implementation.

As an example of the process, in the case of the Kallang / Paya Lebar Expressway, it was found to be more economical to construct the expressway underground compared to above ground after taking into account the savings in land take, the environmental impact and other factors. In the Cost Benefit studies, it was demonstrated that going underground appeared to be an attractive option. However, even for underground construction, the LTA also faces many challenges as road development projects have to compete for space with underground Mass Rapid Transit (MRT) tunnels, electricity cable tunnels, Deep Tunnel Sewerage System (DTSS) and the link sewer network.

2.1.2 Use of Latest Construction Technology

One of the main challenges faced by the LTA is to minimise the impact of road works on the surrounding environment. With the heavy traffic along most of the roads, the LTA has to ensure that there is no reduction in the existing number of traffic lanes during construction works so as to minimise disruptions to motorists. With these constraints, the contractor is often given a very narrow working corridor.

The Singapore Government embarked on a huge road building plan in the 1960s to provide the outlying areas with more amenities and provide access to all parts of Singapore. Up to the late 1960s, there were only a handful of large local civil engineering and building contractors. The projects were generally not complex and the construction techniques used were straightforward. The construction industry slowly opened itself up and gradually adopted new construction methods and techniques. These included the use of computerised project management and design tools, extensive use of prefabrication and wider use of mechanised equipment. In recent years, the road development projects have seen the introduction of highly mechanised and prefabrication construction technology in the construction of bridges, flyovers and viaducts. In Singapore, the use of prestressing concrete technologies for bridges started in the 1950s while the use of precast concrete segmental bridge construction began in the late 1970s. The next sections provide an overview of the evolution for the bridge, flyover and viaduct construction methodologies in urbanised Singapore.

2.2 History of FLYOVER, bridge and viaduct construction in Singapore

The early application of prestressed concrete technology was in the construction of Merdeka Bridge using precast pre-tensioned beams in the 1950s. Designed and constructed by the then Public Works Department, it has played a vital role in introducing the use of prestressed concrete technology in Singapore. The introduction of the system has resulted in the construction of longer bridges with economic use of construction material. With the successful completion of Merdeka Bridge, many other bridges were built using prestressed concrete technology.

Works on Singapore's first flyover began in 1967 at the Jalan Toa Payoh, Thomson and Whitley Road interchange. The construction was carried out by means of precasting the prestressed beams at the casting yard and later launching using cranes. In the 1970s, many more flyovers and bridges were built with the construction of expressways such as the Pan-Island Expressway (PIE) and East Coast Parkway (ECP). The introduction of segmental construction technology into Singapore was through the construction of the Benjamin Sheares Bridge in 1977, which forms part of the ECP.

3. SEGMENTAL BRIDGE, FLYOVER AND VIADUCT CONSTRUCTION TECHNOLOGIES

Segmental concrete bridge construction has become a very important method in spanning deep valleys, wide water crossings, and across highways and existing junctions without the use of costly and extensive falsework.

The concept of segmental bridge construction began in Europe in 1950s. The first cast-in-place segmental concrete bridge was built across the Lahn River in Balduinstein, Germany in 1950. The first precast segmental concrete bridge was built to cross the Seine River, France in 1962. Since then the concept of segmental bridge construction has spread from Europe to all parts of the world.

In 1973, the first U.S. precast segmental concrete bridge was built and opened to traffic in Corpus Christi, Texas. In 1974, the first U.S. cast-in-place segmental bridge was built and opened to traffic near San Diego, California. Since then, hundreds of precast and cast-in-place segmental concrete bridges have been constructed throughout the USA. Improvements and refinements in design and construction have been made over the years.

3.1 Benjamin Sheares Bridge

The development of segmental bridge construction in Singapore also mirrored those in Europe and the United States. The first segmental bridge construction project started in 1977 through the construction of the then Singapore's longest elevated viaduct, the Benjamin Sheares Bridge. The bridge extends 1.75km across Kallang Basin and the Singapore River over twenty-three spans and the piers and foundations were built on reclaimed land.

It provided a great challenge to the construction team as it has to accommodate the navigational needs of the busy shipyards inside Kallang Basin and the harbour. In order to meet the 62m wide navigational requirements, tapering H-shaped trestles were conceived to provide supports to the elevated bridge decks off shore (see Plate 1). A fendering system was also provided on the faces of pilecaps adjacent to the main shipping channels. The construction of the pilecaps required fine co-ordination and planning as the concreting of the pilecap had to be completed within the six hours of low tide available twice daily.

A new dimension of viaduct construction was introduced. The contractor made heavy investments to mechanise the construction work. The elevated viaduct linking Tanjong Rhu to Marina Centre is made up of two basic elements: the trestle decks and prefabricated beams (see Figure 1). The trestle decks consist of tapering H-shaped columns on which 39.5m long hollow box girders are constructed and assembled from 3m long prefabricated segments. Each trestle deck comprises three to six rows of hollow box girders. Each hollow box girder is made up of 13 numbers of 27 tonne segmental box girder units with two end

blocks at each end. The precast elements are lifted and placed directly by a crane onto a set of gigantic metal falsework supported by trestle legs.

Plate 1. The H-shaped trestle deck under construction

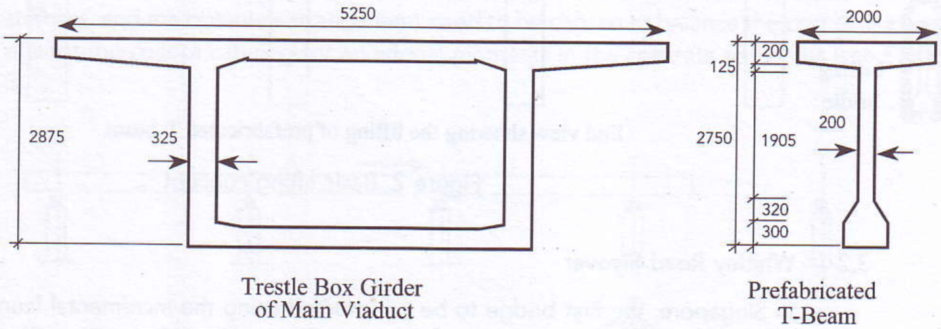


Figure 1. Typical element dimensions

The prefabricated beams consisted of 78 numbers of T-beams of varying length of 41m to 47m and weighing 153 to 175 tonnes each are used to connect the trestle decks to form the crossing over the Kallang Basin. The T-beams were lifted and set into position by means of a positioning gantry of triangular steel truss. The transporting and positioning operation is carried out as follows:

The beams are brought forward on rails of a track at ground level along the line of the bridge on shore and by barge, off shore. Each beam is lifted onto the deck by the positioning gantry, which rests at its end of slide track extending transversely across the trestle decks and projecting laterally beyond them (see Figure 2). The positioning gantry together with the prefabricated T-beam is moved sideways and the beam is placed into position.

The timely completion of the project in 1981 was seen by many as an engineering marvel. Many at that time also hailed that the structure was the most splendid structure ever built in Singapore in the past twenty years. Since then, many other viaducts has been built using segmental construction technologies in Singapore and the following sections highlight some of the more recent LTA projects - both completed and ongoing.

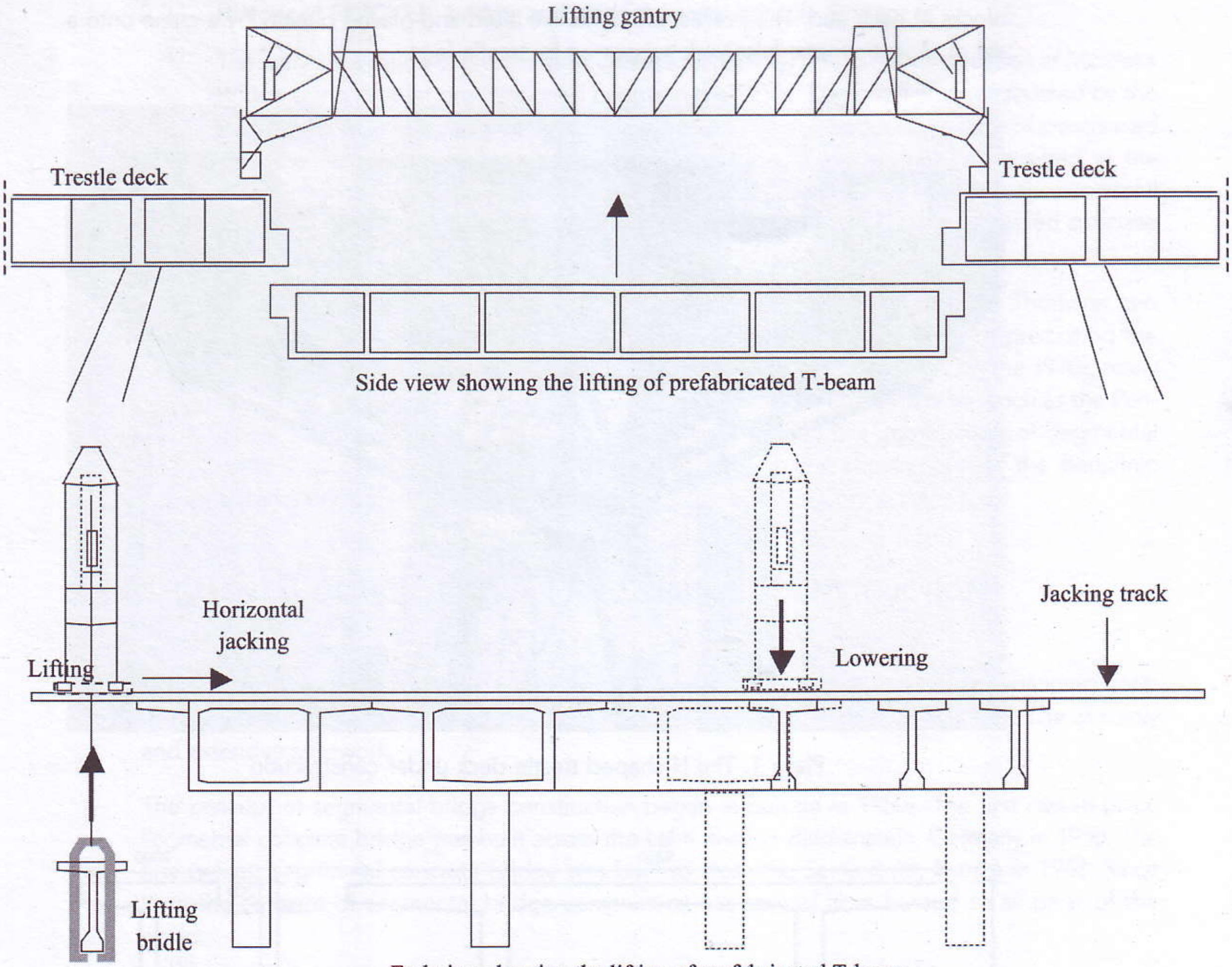


Figure 2. Basic lifting concept

3.2 Whitley Road Flyover

In Singapore, the first bridge to be constructed using the incremental launching method was carried out in 1987 for the Whitley Road Flyover. The Whitley Road Flyover consists of a pair of parallel flyovers at the Bukit Timah Road/Dunearn Road/Whitley Road/Stevens Road interchange. As the above road junction is a very busy intersection, the disruption to vehicular traffic must be kept to a minimum during the construction stage. The successful tenderer proposed the use of incremental launching method for the construction of the main elevated girder in order to minimise the disruption to traffic below (see Plate 2).

In the cross-section, the main elevated structure is a single-cell box beam with two identical side cantilevers and diaphragms at the centre of each pier. The box beam has a constant depth of 1.8m and a width of 7m at the soffit. The overall width of the flyover is 13m, consisting of a carriageway and footpath. The carriageway width is 10.5 m and consists of 3 traffic lanes of 3.5 m each.

The main elevated structure is divided into seventeen segments. The extrusion platform (i.e. the prefabrication area) was situated behind one of the abutments. It was bounded by the two side walls of the approach structures, the abutment wall and the return wall at the rear. Within the extrusion platform, the stationary casting yard was set up for the casting of concrete segments. The stationary casting yard consisted of:

- timber formwork with stiffeners to cast the box beam and side cantilevers
- a grid system consisting of structural steel sections to carry the self-weight of the formwork and weight of the wet concrete of the segments; and
- a system of eight hydraulic lifting jacks evenly spread out to transmit the loads from the steel grid to the temporary concrete support. The jacks were used for raising, lowering and adjusting the formwork.

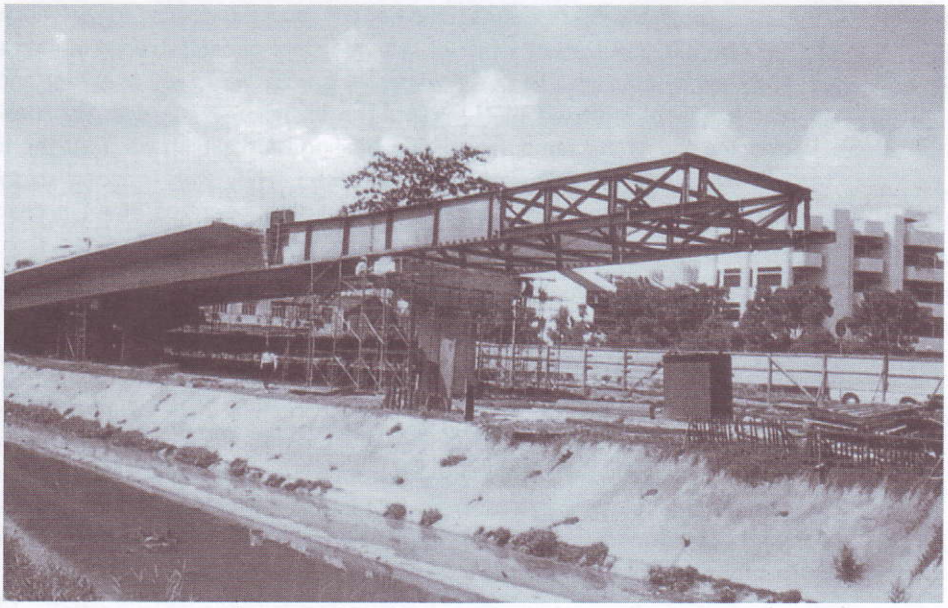


Plate 2. Steel launching nose for the construction of Whitley Road Flyover

The concrete segments were cast in two stages. The first stage is the casting of the bottom slab, webs and diaphragms. The second stage included the casting of top slab and side cantilevers. To reduce the bending and shear forces in the leading segment during launching, a steel launching nose was firmly secured to the front face of the segment to be launched. The effectiveness of the launching nose is governed by its length and stiffness, and the optimum arrangement need to be chosen to balance the cost of the nose against the cost of catering for additional moments in the concrete segments (see Figure 3).

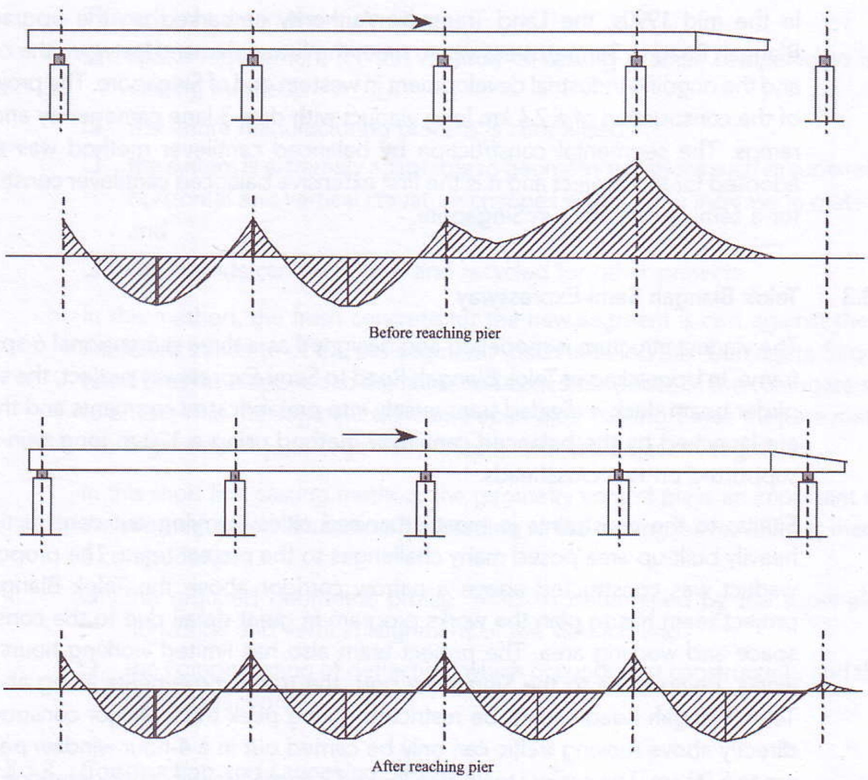


Figure 3. Bending moment range during incremental launching

Based on the project team's cost-benefit analysis, a 24m long launching nose was designed. It consisted of a pair of stiffened steel girders, straight in plan and connected together by bracings. The front part of the nose was a lattice girder and the rear part was a pair of stiffened plate girder. The launching nose was also designed to slide over the top of the temporary sliding bearings and sliding pads. At the tip of the nose, two 25 tonne hydraulic jacks were attached. They were needed to raise the tip of the nose to slide over the temporary sliding bearings when it reached the pier support.

The pulling mechanism for launching the concrete segments forward consisted of two hydraulic jacks, two pulling tendons and two steel I-section stumps. The hydraulic jacks anchored at the front face of the abutment provided the pulling force.

In the extrusion process, the downward component of the self weight of the segment assembly and the frictional resistance of the sliding surface had to be overcome. Temporary sliding bearings were positioned at the soffit of the segment and consisted of a top and bottom steel plate with a rubber pad sandwiched in between. The temporary bearings were placed at each pier and at eight numbers of temporary supports in the extrusion platform.

Unevenness of the concrete surface and differential settlement of the piers and temporary supports can generate additional moments and shears during the launching operation. All these factors need to be considered in the design. During the launching operation, the pier head deflection and pier settlement were constantly monitored to ensure that they were within the allowable limits. When the launching was completed, the bridge was jacked up at one support at a time to remove the temporary bearing and replaced with the final pot bearing.

The construction of the Whitley Road Flyover has opened a new chapter in the bridge construction for Singapore contractors. Subsequently, another three-tier interchange was also successfully constructed using similar incremental launching method at the Holland Road/Farrer Road/Queensway junction in 1994.

In the mid 1990s, the Land Transport Authority embarked on the upgrading of Telok Blangah Road to Semi-expressway to meet the future demand between the container ports and the ongoing industrial development in western end of Singapore. The project comprised of the construction of a 2.4 km long viaduct with dual 3-lane carriageway and 4 associated ramps. The segmental construction by balanced cantilever method was evaluated and adopted for this project and it is the first extensive balanced cantilever construction project for a semi- expressway in Singapore.

3.3 Telok Blangah Semi-Expressway

The viaduct structure is modelled and designed as a three dimensional 6-span continuous frame. In Upgrading of Telok Blangah Road to Semi-Expressway project, the single cell box-girder beam deck is divided transversely into prefabricated segments and these segments are launched by the balanced cantilever method using a 120 m long twin-truss, which is supported on two crossheads.

Similar to the constraints in most urbanised cities, carrying out construction works in a heavily built-up area posed many challenges to the project team. The proposed overhead viaduct was constructed above a narrow corridor above the Telok Blangah Road. The project team has to plan the works program in great detail due to the constraints in land space and working area. The project team also has limited working hours for launching works. Being close to the Singapore port, the traffic movements along at-grade six-lane Telok Blangah Road cannot be restricted during peak traffic. Major construction activities directly above moving traffic can only be carried out in a 4-hour window period from 1.00 am to 5.00 am. The project team also looked into many safety considerations during viaduct construction as works have to be carried out at height above heavy trafficked Telok Blangah Road.

This method of segmental construction and launching by balanced cantilever is adopted for the project due to the following:

- Without falsework erection at ground level, existing traffic along Telok Blangah Road can be maintained. Dividing the beam deck into relatively smaller units allows these smaller segments to be lifted at low-traffic period during the night where lanes directly below these segments are closed. All traffic lanes can be reopened for traffic in the day time;
- Segments only need to be delivered in the night of launching to avoid occupying the narrow centre median of Telok Blangah Road. This allows more space for machinery accesses within the centre median during the day time and also improves the tidiness of the site. Launching truss can skip to other piers for launching when faced with obstacles, allowing flexibility in this construction method;
- Longer spans, up to 45 m can be built across major junctions;
- Shallower beam depth at supports can be constructed by integrating the crossheads and segments at same level. A lower viaduct from the ground level road to deck level can be built while maintaining the minimum vertical clearance;
- A more aesthetically pleasing and economical structure is attainable;
- Lower maintenance effort on bridge bearings and movement joints as they are installed only at expansion joints located at every sixth span of the viaduct; and
- Better quality control of prefabricated components in a conducive factory environment, thereby having better off-form surface finishes and greater dimensional accuracy in the segment production.

3.3.1 *Fabrication of Segments*

There are 6 types of single cell box-girder segment designs and the typical length of the segment is 3.3 m. The width of each segment at the deck level is 12.8m and it is able to accommodate three traffic lanes. Each segment weighs 50 to 60 tonnes. The segments are cast by short line casting in the off-site precast yard. In short line casting method, the mould is stationary while the segment moves from the casting position to the match cast position and then to storage area.

The advantages in this method are:

- space requirement for this method of casting is small compared to long line casting method;
- the entire manufacturing process is centralised;
- the system is extremely adaptable to geometry variations such as super-elevation, horizontal and vertical curvature changes without any increase in material cost; and
- the moulds can be reused and recycled for other projects.

In this method, the fresh concrete for the new segment is cast against the already hardened concrete of the old segment, which is called the 'Conjugate Segment.' A bond breaker is applied to the hardened concrete surface of the conjugate segment to ensure that the segment will come apart after casting. Since they are match cast, the segment will joint together perfectly with the adjacent segment.

In this short line casting method, the geometry control plays an important role and the segments are manufactured according to the casting curve, which is made up of 2 components:

- the required geometric profile, which is determined by the super-elevation, horizontal and vertical alignment of the viaduct; and
- the compensation of deflection, which occur during construction, and the long-term deflection.

3.3.2 *Construction and Launching Sequence*

There are three stages of launching for the construction of the viaduct:

- launching of crosshead
- lifting of 1st pair segments by hangar beams system
- installation of 2nd to 6th pair of segments by moving gantry system

3.3.3 *Stage 1: Launching of Crosshead*

The upper half of a typical crosshead is cast-in-place whereas the lower half is prefabricated. The 26 m long prefabricated structure at the lower half of the crosshead weighs approximately 150 tonnes. Launching of crossheads were carried out only during low-traffic period at night from 1.00 am to 5.00 am, when the affected lanes are closed. The upper insitu half of the crosshead is cast once the reinforcement and formwork have been erected.

3.3.4 *Stage 2: Lifting of First Pair Segments*

Launching of segments is usually done only after a minimum of 14 days curing to avoid adverse creep effect on the structure. The viaduct is designed to have a 300 mm stitch (wet joint) between the crosshead and the first pair of segments. The stitch is introduced to eliminate the need to match cast the crosshead with the first pair of segments. The stitch is also introduced for the purpose of geometry control after launching and casting of crossheads.

The first pair of segments is installed by the hangar beams system. The hangar beams frame is secured to the top of the crosshead with vertical post-tensioning tendons. These vertical post-tensioning tendons also take care of any unbalanced moment experienced by the hangar beams frame while the segments are being lifted on both side of the crosshead at different time. Hydraulics jacks in the hangar beams hoist the first pair of segments up to be secured in position. The first pair of segments is secured in position with vertical stress bars through holes in the segment deck and segment lifting frame while steel reinforcements are tied and formwork erected before casting of the wet joint.

3.3.5 *Stage 3: Installation of Segments by Moving Gantry System*

The 200 tonnes gantry is 120 m long and is supported on two crossheads, spaced at about 40 m (see Figure 4 and Plate 3). Vertical post-tensioned tendons are used to secure the gantry to the crossheads at the supports. The segment delivered by low-bed trailer is hoisted vertically upwards by the lifting frame of the gantry and moved longitudinally along the gantry. The segment is lowered at the appropriate position and temporarily post-tensioned using stress bars against last permanently post-tensioned segment.

Launching of segments are done only during low-traffic period at night from 1.00 am to 5.00 am when the affected lanes are closed. The cycle time for launching of one span for both east and west bound carriageway segments is one week. Epoxy is applied with a spray gun onto the face of the entire edge of the delivered segment that is ready to be joined to the launched segment. Film thickness of the epoxy was maintained within the range of 0.5 to 2.0 mm. The pot life of the epoxy used for this project is 1 hour and within this 1 hour, the segment has to be launched and temporarily post-tensioned.

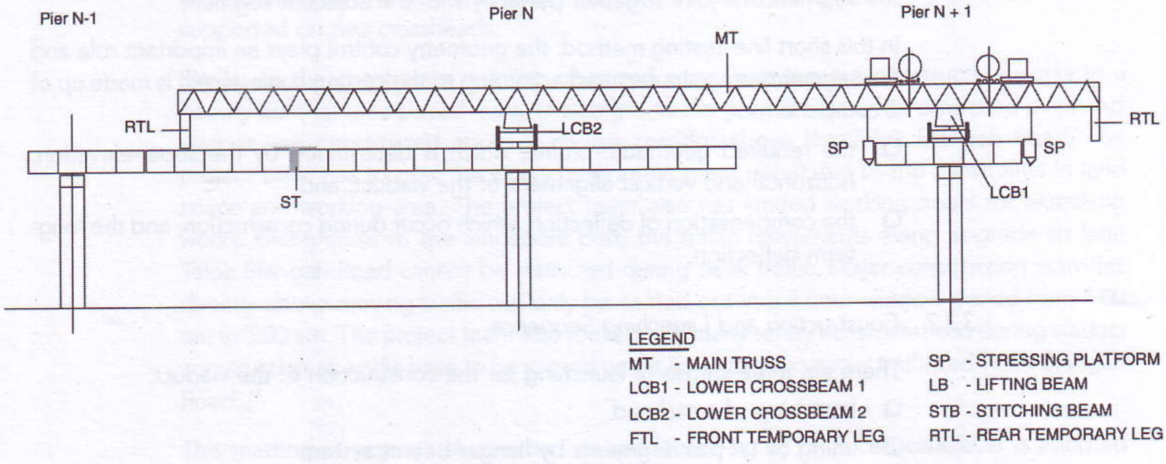


Figure 4. Segment launching using balanced cantilever method

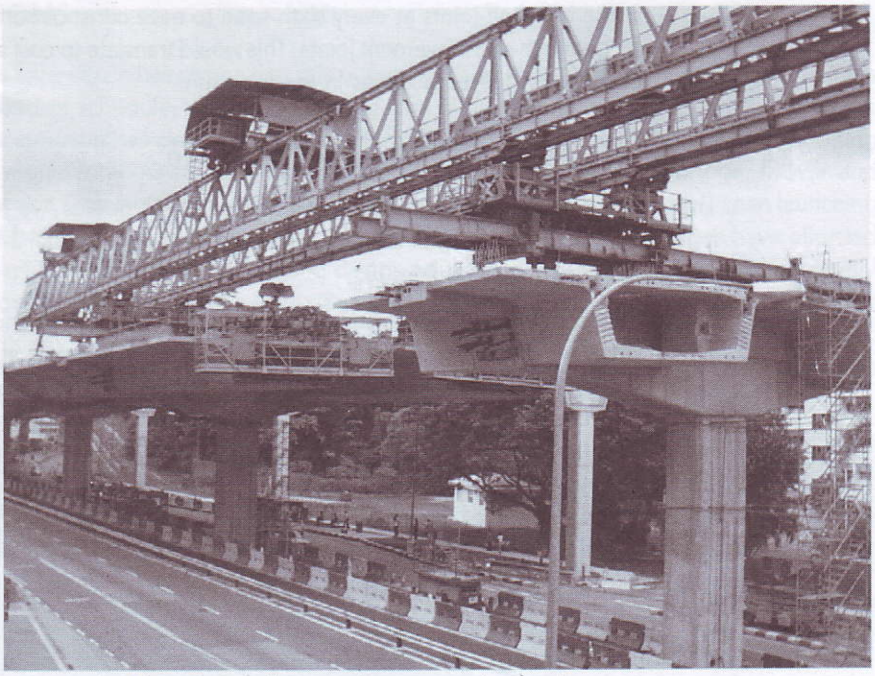


Plate 3. Installation of segments by moving gantry system

3.3.6 *Post-Tensioning Works*

It is common practice to use temporary stress bars to secure the erected segment before the main longitudinal post-tensioning tendons are installed. The purpose is:

- To provide a rapid means of transferring the weight of the segment from the lifting gantry to the structure within the pot life of the epoxy. This way, the gantry is then able to be shifted to the next bound for installation of the segments while the permanent longitudinal post-tensioning is being installed in the segments of the former bound; and
- To allow a fairly even compressive stress of about 0.5 MPa to be applied over the whole joint epoxy glued joint face and let the epoxy sets under uniform compression. If the compressive stress is significantly non-uniform in balanced cantilever construction, then the epoxy joint thickness tends to vary and this may affect the desired alignment of the segments after several segment installation.

Permanent post-tensioned tendons are installed and stressed as erection of segment proceeds. Both internal and external tendons are used in this project. Internal tendons are located in the ducts within the flange and web of the segment. External tendons were used to provide continuity for 6 spans of viaduct box-girder. The external tendons in polyethylene pipes were laid through pier diaphragm and the deviator blocks provided inside the box-girder.

At the end of launching of all segments in one span, the deck level difference of the last launched segments in midspan usually falls within the range of (50 mm. The deck level can be adjusted by using stress bars through holes in the deck and stitching beam which spans across the 1m closure pour gap in the middle of the span. This is done by controlling the amount of force exerted by the hydraulics jacks on stress bars until the deck levels between adjacent viaduct structures match in alignment. Stitching beam will be removed after the closure pour has been cast and the mid-span permanently post-tensioned.

The benefits of using prefabricated segmental construction by balanced cantilever method became more apparent with the timely and successful completion of the project in December 2001. In the process, several innovative ideas were successfully explored and implemented such as the use of semi-prefabricated crosshead so that it can be launched easily using cranes. The viaduct was designed as continuous

frame with half-joints at every sixth span to ease construction and reduce the need for bearings and movement joints. This would translate to cost savings in maintenance of these bridge accessories in the long run.

3.4 Viaduct from Airport Road to Tampines Avenue 10

The viaduct construction project from Airport Road to Tampines Ave 10 is currently ongoing. It involves the construction of a 2.1km long road viaduct with dual 3-lane carriageway from Airport Road to Tampines Ave 10.

The viaduct superstructure consists of a triple cell main segment and two wing segments. All the piers are cast insitu. The precast segments are fabricated at the casting yard and were erected by means of span-by-span launching method. The viaduct was designed as a frame structure. Similar to the Telok Blangah Semi Expressway viaduct, the number of half-joints in the viaduct was reduced considerably. The structure requires only one half-joint for every seventh span. This also allowed the overall depth of the main segment to be reduced and hence provide economic savings, as less construction materials are required. Aesthetically, it is also pleasing with its slim design.

In the long run, the maintenance of the viaduct would be reduced as the frame design concept reduced number of bearings and expansion joints required. This is in comparison with the conventional design where the structure sits on the bearings on each of the columns.

3.4.1 *Production and on site installation of precast structures*

The on site casting yard is arranged to facilitate the following:

- Segment production rate to match the rate of launching; and
- Completed segments to match the overall viaduct geometry through match casting.

The casting yard consists of three production lines, each with its reinforcement jig, formwork system and survey towers. The production rate is approximately 40 segments/month and sufficient storage space has to be catered for the precast segments.

The wing segments are produced in the wing slab fabrication yard. There are six production lines in the wing slab yard, with approximate production rate of 100 segments per month.

The span-by-span launching method required the whole span, consisting of 13 main segments with total weight of 1235 tons, to be hoisted and stressed longitudinally above ground (see Plate 4). After stressing and final positioning, the whole span will be lowered to sit on the pier structure.

After the main segment erection has been completed, crosshead construction will be carried out. The wing segments will be launched using crane, after certain designated phases of stressing works has been carried out. Transverse stressing to secure the wing segment will then be carried out.

Due to the unique triple cell box shape structure of the main segment, it poses some challenges in achieving satisfactory concrete finishes. Concrete mix design and casting sequence are reviewed and improved to achieve the required concrete finishes.

Maintaining the geometry between the main segment, and the geometry between the main segment and the wing segment also posed a great challenge. In order to meet this requirement, stringent geometry checks on the precast segments are carried out regularly.

Another challenge is the hoisting and stressing above ground of the whole span, which consists of 13 segments with a total weight of 1235 tonnes. It can be considered as one of the heaviest segment lifting in Singapore ever recorded to date.

The project is progressing well with the ongoing span-by-span launching of the precast segments. The successful applications of the segmental construction and various launching methods in LTA projects offer considerable scope for similar works in the future.

4. CONCLUSIONS

The Singapore experience has shown that it is possible to complete segmental concrete structures on time or ahead of schedule, within budget and with minimum inconvenience to the motorists. Segmental construction has demonstrated its effectiveness against other alternatives in bridging space and environmental constraints in heavily built-up areas. In Singapore, bridge, flyover and viaduct construction using incremental launching, balanced cantilever and span-by-span launching methods have been successfully carried out. Occasional difficulties and challenges have afforded many opportunities for both the project and design team to learn and improve. Through careful planning and design, the segmental construction scheme has proven to be an economical, efficient and practical solution to the challenges of road development projects in an urbanised Singapore. The successful applications of both precast and cast-in-place segmental construction and various launching methods in LTA projects will offer considerable scope and options for the future.

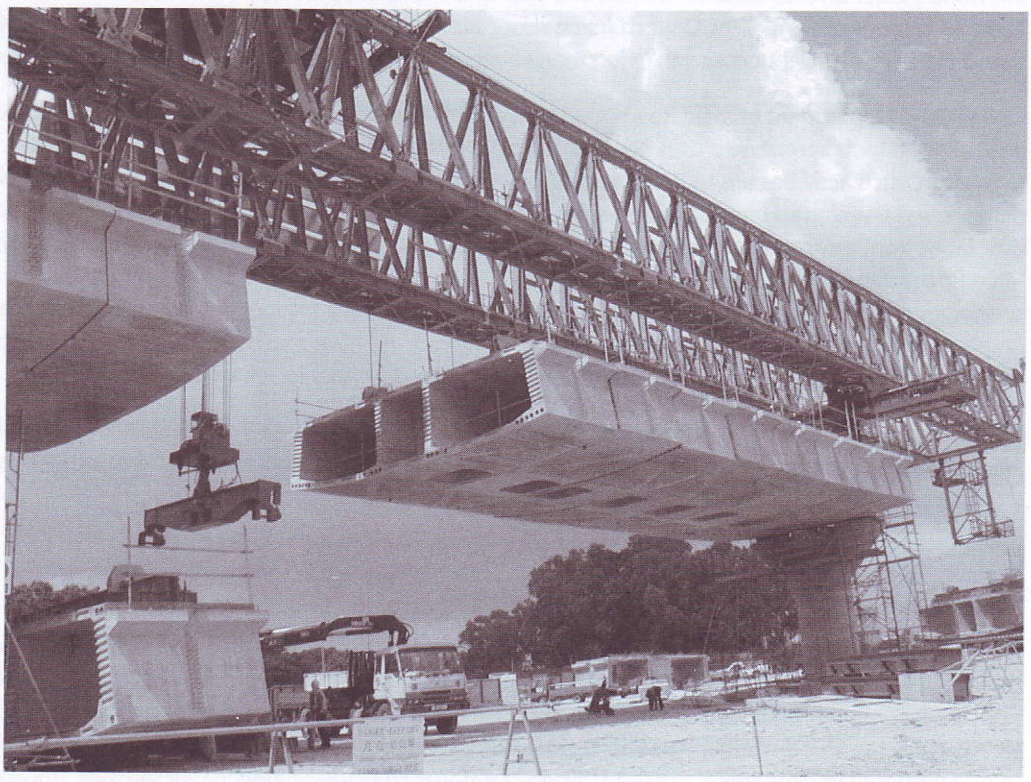


Plate 4. Installation of the precast segments using the span-by-span launching method

REFERENCES

Public Works Department, Singapore (1980). East Coast Parkway Project, Phase IV, Some Aspects of Construction of the Main Viaduct. 5th PWD Technical Seminar.

Walter, P. and Jean, M.M. (1982). Construction and Design of Prestressed Concrete Segmental Bridges. John Wiley and Sons.

Jacques, M. (1983). The Cantilever Construction of Prestressed Concrete Bridges. John Wiley and Sons.

Public Works Department, Singapore (1987). Incremental Launching of Whitley Road Flyovers.

Lim, E.W. and Ganeshalingam, R. (1990). Prestressing in Singapore. Prestressed & Precast Concrete Society.

Chen, W.F. and Duan, L. (1999). Bridge Engineering Handbook. CRC Press.

UK Highways Agency (1999). Post Tensioned Concrete Bridges. Anglo-French Liaison Report, Thomas Telford Publishing.

ACKNOWLEDGEMENTS

This paper was originally published in the Proceedings of the 21stARRB/11th REAAA Conference, cairns, Australia, May 2003 (ARRB Transport Research Ltd).

The authors of the paper would like to thank the Deputy Chief Executive of the Land Transport Authority for the permission to publish this paper.

Road Maintenance Code of Practice for the Wet Tropics World Heritage Area

Karen Oakley
Queensland Department of Main Roads, Australia

ABSTRACT

The Wet Tropics World Heritage Area (WTWHA) in far north Queensland is recognised for its natural values of international significance, including rainforest, mangrove forest and eucalypt forest. It is one of the world's most diverse areas of animals and plants, and provides records of how the earth has evolved. The area is protected under the United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Convention and the Commonwealth of Australia has committed to this agreement.

Queensland Department of Main Roads manages a significant road network within the WTWHA. Activities involved in the maintenance of this network have the potential to cause harm to the environment. Under legislation, such activities are to be governed by a code of practice (code). A code for the WTWHA road network was developed under extensive consultation with road maintenance engineers and work crews, with input from environmental specialists. The product is a field guide that demonstrates why and how Main Roads should undertake maintenance activities to minimise adverse environmental effects on this special area. Key features of the code include simple step-by-step instructions and maximum use of the graphical medium. The various maintenance activity instructions have also considered beneficial secondary effects, such as enhanced visual amenity for road users and visitors to area.

The code assists the department to comply with the stringent requirements of legislation governing the area, achieve environmental protection, while providing a safe and efficient road network. This paper discusses these benefits and the process of developing the code.

1. INTRODUCTION

Queensland Main Roads manages a significant road network within the Wet Tropics World Heritage Area. Activities involved in the maintenance of this network have the potential to cause harm to the environment. Under legislation, such activities are to be governed by a code of practice. In October 2002, the Queensland Department of Main Roads in association with the Wet Tropics Management Authority implemented a revised "Road Maintenance Code of Practice for the Wet Tropics World Heritage Area", providing instruction for protecting this unique environment.

2. THE NEED FOR A CODE OF PRACTICE

2.1 The Importance of the Wet Tropics World Heritage Area

The Wet Tropics World Heritage Area (WTWHA) is an area of 900,000 hectares stretching between Townsville and Cooktown in far north Queensland, Australia. The area includes rainforest, mangrove forest and eucalypt forests. The wet tropics area has been included on the World Heritage List due to its natural values of international significance. The WTWHA is also important for its diverse cultural history and significance to indigenous Australians (Wet Tropics Management Authority, 1999).

The WTWHA is one of the world's most diverse areas of animals and plants. It is home to 30% of Australia's marsupials; 25% of Australia's frogs; 62% of Australia's butterflies and approximately 50% of Australia's birds. Land features, plants and animals found in the WTWHA provide scientists with a record of how the earth has evolved. Some plant species found in the WTWHA have existed for millions of years (Wet Tropics Management Authority, 1999).

The area continues to be important both nationally and internationally for natural heritage, recreational, and various scientific research purposes.

2.2 Governing Legislation

In 1974 Australia adopted the United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Convention. This Convention is recognition of the need to identify and permanently protect the world's special areas. With respect to the WTWHA, Australia's commitment is recorded in the *World Heritage Properties Conservation Act 1983 (Commonwealth)* and the *Wet Tropics of Queensland World Heritage Area Conservation Act 1994 (Commonwealth).*

In parallel, the *Wet Tropics World Heritage Protection and Management Act 1993 (Queensland)* was legislated which established the Wet Tropics Management Authority (WTMA). The Authority then developed and implemented the *Wet Tropics Management Plan 1998* as a vehicle for managing the WTWHA,

2.3 Permit for Road Maintenance Activities

Under the *Wet Tropics Management Plan 1998*, a permit is required to maintain roads and clear vegetation along roadsides within the WTWHA. The Plan provides that:

- A person must not maintain a road within the Wet Tropics World Heritage Area unless it is lawfully carried out under a permit [Section 26(1)(g)].
- A permit may be issued to a person to clear vegetation around a road to the extent necessary for its appropriate use [Section 33(e)].
- A condition of the permit obtained by Queensland Department of Main Roads (Main Roads) is that road maintenance activities in the WTWHA must be undertaken in accordance with an approved code of practice.

2.4 The Impact of Roads on the WTWHA

Roads can have both positive and negative impacts on the values of the WTWHA. Well-maintained roads not only provide access to the community and tourists, but also enhance the visual values of the area. However, there are also several ways by which roads negatively impact on the values of the WTWHA. Of great concern is the risk of reduction of biodiversity. In appreciation of scientific research and observation, the Code considers the following (Rainforest CRC, 1998 & 2000).

Roads create barriers to animal movement

For example, the movement of many species is inhibited by roads, particularly arboreal (tree dwelling) species. This barrier can mean that groups inbreed; or that foraging areas are restricted thus altering ecological systems.

Roads create disturbed areas that allow weeds and pests to establish

For example, pests such as toads can inhabit weedy grasses along roadsides. Weeds and pests compete with native species for habitat and food. They can also alter conditions so areas along roads are no longer suitable for some local native species; for example, weedy areas promote fires that change vegetation types.

Roads increase erosion in areas

For example, high rainfall can continually erode steep road embankments in erosion prone soils common in the WTWHA. Erosion causes loss of topsoil and land area. Erosion can also cause sediment build-up in waterways. High sediment loads can prevent water from reaching habitats and can restrict and sometimes kill aquatic animals and plants.

Road runoff carries contaminants from vehicle emissions and spills

For example, hydrocarbons emitted from vehicles can be washed into adjacent watercourses. Contaminated water travels along road surfaces and table drains to waterways where it may harm and sometimes kill native animals and plants.

Collisions with vehicles cause animal deaths

For example, road kills threaten the survival of Mission Beach cassowaries of the WTWHA. As the number of road kills increases, the biodiversity of the WTWHA is reduced.

Roads affect significant areas and/or people's lifestyles

For example, a road may pass nearby an area of ceremonial or historical importance. Effects may be direct, such as physically altering a site; or indirect by affecting its quality, for example, increasing background noise or light conditions.

Roads change conditions of adjacent natural areas

For example, road noise can be detected more than 100 metres into a forest. The gap in a forest caused by a road allows sunlight to enter. This light can alter plant life growing some distance into the forest. Also, noise, dust and lights from traffic can disturb plants and animals within forests adjacent to roads. The 'edge-effected' forest beside roads adds up to a significant proportion of the WTWHA.

3. DEVELOPING THE CODE OF PRACTICE: CONSULTATION

The "Road Maintenance Code of Practice for the Wet Tropics World Heritage Area" (the Code) was developed in consultation with Wet Tropics Management Authority; Main Roads' engineers, supervisors, work crews and environmental officers; and various environmental specialists from external government agencies and universities.

The aim of the consultation was to develop requirements that minimise environmental harm and satisfied WTMA but were still practical for Main Roads' operations. As a result, the Code first provides the user with an understanding of how roads currently impact the WTWHA environment; and then explains how and why maintenance activities are to be undertaken to assist with reducing impacts.

3.1 Main Roads' Maintenance Activities in the WTWHA

Main Roads maintenance activities are undertaken in accordance with the "Road Maintenance Performance Contract" (RMPC). Consultation with engineers and maintenance staff regarding how maintenance activities are undertaken enabled activity-type sections of the Code to be developed. The Code adopted 7 maintenance activity-type sections (see below) closely aligned to the RMPC activity-types.

Maintenance activities were then discussed with environmental specialists from WTMA, the Queensland Parks and Wildlife Service (Centre for Tropical Rehabilitation), and the Rainforest Co-operative Research Centre. Consultation determined any specific adjustments that may assist Main Roads address WTMA concerns. Examples are provided within the maintenance activity-types below.

3.1.1 Roadside Works

Roadside Works includes any maintenance activity off the road formation but within the road reserve, for example, vegetation management activities.

Example: Environmental specialists advised that trimming methods (ie side-arm slashing) undertaken by some maintenance crews in the WTWHA was inappropriate. The use of a side-armed slasher fractures branches, providing the opportunity for many new branches to re-sprout, causing repetitive work; or allowing disease to enter the tree more easily.

It was further advised that manual trimming, although initially more labour intensive, would assist in maintaining 'healthy' vegetation and essentially train trees to grow across the road corridor, without obstructing safety zones (see Section "Avoid disturbance" for more information). In turn, the frequency of roadside trimming required in areas would be significantly reduced (e.g. reduced from 6-12 months, to 3-5 years).

3.1.2 Bridge Works

Bridge Works are maintenance activities on any component of a bridge structure, for example, bridge servicing[1].

[1] Works that require disturbance to watercourse banks or beds (eg. reinstating timber piles) are considered major works and require further advice from WTMA (ie such works are not covered within this Code of Practice).

Example: Many maintenance activities undertaken on bridge structures (e.g. chemical treatments; painting; cleaning) have the potential to cumulatively impact on the watercourses of the WTWHA.

It was requested that *all* works remain on bridge decks, to reduce impact to bed and banks, and that *all* drips, spills and debris be captured to prevent contamination of watercourses.

3.1.3 *Drainage Works*

Drainage Works is repair, installation and/or replacement of parts of the road drainage system, including culverts, floodways and erosion and sedimentation control devices.

Example: The necessary cleaning of culverts has the potential to contaminate waterways with sediment, impacting on aquatic flora and fauna. The nature of soils within the WTWHA means this is a frequent and ongoing activity.

WTMA advised that watercourses could manage small loads of sediment, similar to that experienced naturally. WTMA agreed that if culverts contained sediment build-ups of less than 1/3 height of the culvert, regular maintenance activities could be undertaken. Further, in instances where loads in culverts were permitted to exceed 1/3 height of the culvert, additional capture and removal activities would need to be employed.

3.1.4 *Road Furniture Works*

Road Furniture Works is installation, repair and/or replacement of road furniture items along the roadside, for example, guardrail.

Example: Installations such as fences, guideposts, and culverts have the potential to disturb vegetation and/or add sediment loads to watercourses.

WTMA requested that Main Roads sandbag areas likely to generate large areas of loose soil, prior to excavation. All material is to be reused or removed from the WTWHA. Pushing spoil off the road formation is not permitted, as it can be carried into waterways or damage vegetation.

3.1.5 *Sealed Road Surface Works*

Sealed Road Surface Works are any activities that maintain pavements, for example, pavement edge repair.

Example: Hydrocarbons contained within bitumen, while wet, have the potential to be washed into creeks by rainfall. This is particularly hazardous for frog species.

WTMA requested that Main Roads do not spray bitumen if rain is forecast 24 hours before or after the proposed date of spraying. In addition, when regularly cleaning the bitumen spray bar - all waste product is to be captured in sand and removed from the WTWHA.

3.1.6 *Unsealed Road Surface Works*

Unsealed Road Surface Works are maintenance activities on an unsealed road formation, for example, shoulder grading.

Example: Excessive road shoulder grading increases the occurrence of edge-effected forest.

Environmental specialists requested that shoulder grading be restricted to the outer edge of the table drain. This in turn protects vegetation and valuable native seed banks.

3.1.7 *Non-Surface Disturbance Works*

Non-surface Disturbance Works are maintenance activities that do not physically add to or remove from the road formation or roadside. These activities generally involve observing or inspecting, for example, overgrowth of safety clearance zones.

Example: Observation and inspection activities do not require special care in the WTWHA if vehicles do not leave the road formation[2]. However, Main Roads can provide a valuable service to WTMA and other scientific researchers by reporting back on known or suspected areas of:

- ❑ cultural heritage,
- ❑ weed infestations,
- ❑ dieback, and
- ❑ fauna crossings/corridors.

3.2 The "Footprint of Disturbance"

An initial measure to ensure negative impacts on the values of the WTWHA is to ensure works remain within the *"footprint of disturbance"*. The Code defines the *"footprint of disturbance"* as the existing area of impact, which includes the road formation (carriageway, shoulders and table drains); cleared roadsides; and/or cuttings. Main Roads' maintenance works must remain within the 'footprint of disturbance' because the *Wet Tropics Management Plan 1998* states:

1. Section 65(1): the Authority (WTMA) may issue a permit only if the roadworks under the permit would not have a net adverse impact on the integrity of the area or there is no prudent and feasible alternative.
2. Section 65(2): to the greatest possible extent, roadworks be confined to land already cleared or otherwise degraded.
3. Section 65(3): the Authority may permit canopy clearing only if it is satisfied that:
   a. this is needed for public safety, provision of a community service, access to a residence or an activity the Authority considers necessary to properly manage the area under this plan; or
   b. this will reduce the impact on the area's integrity of other activities being carried out or likely to be carried out.

3.2.1 *Works Outside the 'Footprint of Disturbance'*

The Code assists the user in determining whether works will remain with the "footprint of disturbance" by use of simple graphics, which identify 'no-go' areas (see Figures 1 and 2), and decision-aiding flow charts for each maintenance activity-type. When works fall outside of the "footprint of disturbance" they are not covered by Main Roads' permit to maintain roads in the WTWHA and the Code of Practice does not apply.

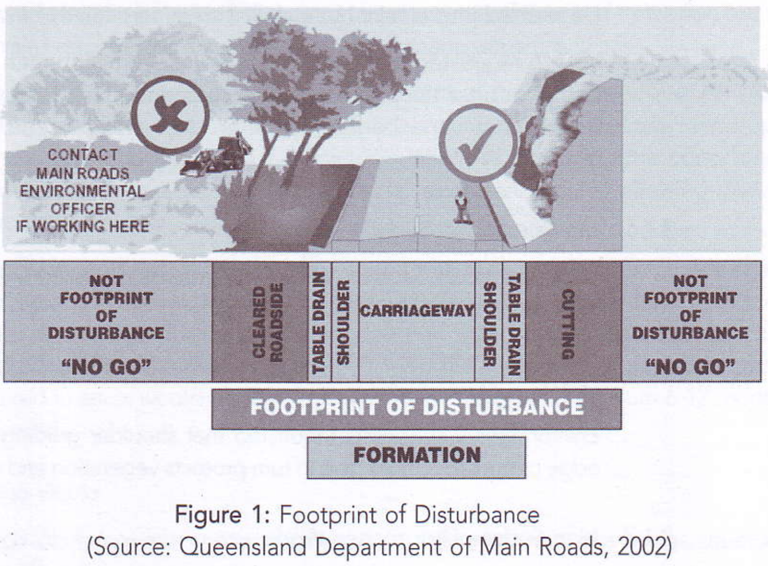


Figure 1: Footprint of Disturbance
(Source: Queensland Department of Main Roads, 2002)

[2] Leaving the road formation may cause vehicles to enter weedy areas and carry weed seeds to other areas within the WTWHA.

The following works are considered outside the 'footprint of disturbance' and require an additional permit from WTMA in the following circumstances.

- ❑ Upgrading, extending or widening of an existing road.
- ❑ Activities requiring canopy clearing.
- ❑ Clearing beyond the existing disturbed or cleared area.

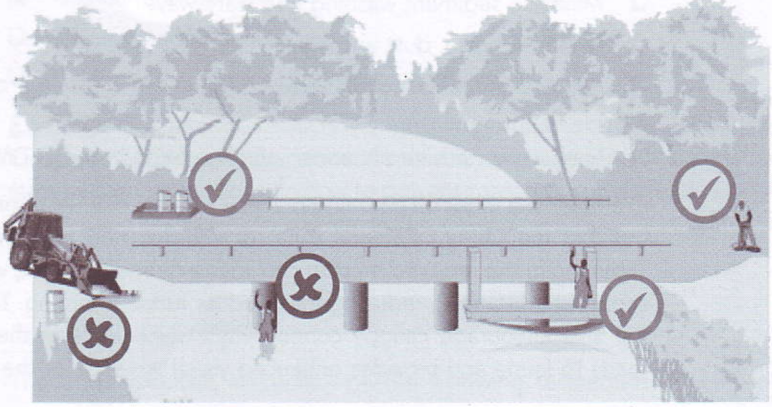


Figure 2: No-go areas at watercourses
(Source: Queensland Department of Main Roads, 2002)

3.2.2 *Works Within the "Footprint of Disturbance"*

As discussed, all Main Roads maintenance activities, excluding non-surface disturbance works, have the potential to disturb values of the WTWHA. By marginally adjusting the way some activities have been undertaken, Main Roads can reduce negative impact on the WTWHA.

During consultation, several requirements to minimise negative environmental impacts while working within the WTWHA were developed. These requirements may also enhance secondary beneficial effects, such as visual amenity for road users. Importantly, it was agreed that Main Roads could address each of these requirements during typical maintenance activities. Relevant requirements are addressed for each maintenance activity-type by tailored and simple, step-by-step instructions, supplemented by specialised appendices[3] and figures.

By implementing these requirements, discussed below, Main Roads can assist with reducing negative impacts on the values of the WTWHA and enhancing positive outcomes. Examples are provided in Section 3.3.

3.3 Requirements for Road Maintenance Activities in the WTWHA

The requirements developed for this Code of Practice aim to directly or indirectly assist in reducing the impacts discussed in Section 2.4. In particular, these requirements will assist with protecting the biodiversity of the WTWHA by encouraging the following.

- ❑ Maintenance of fauna corridors fauna access to food and breeding areas.
- ❑ Protection of waterways and aquatic plants and animals.
- ❑ Reduction of the risk of introducing or spreading disease, pests and weeds.
- ❑ Preservation of areas of significance.
- ❑ Prevention of increased areas of edge-effected forest.
- ❑ Identification of areas of scientific or historical interest.

The requirements will also assist in maintaining or enhancing visual amenity of the WTWHA.

The following sections list the requirements of the Code and provide examples of their implementation.

[3] Appendices provide information on rehabilitating disturbed areas; serious environmental weeds in the WTWHA; identifying cultural heritage places and identifying dieback.

3.3.1 *Avoid Disturbance*

The Code provides instruction on the following techniques for avoiding disturbance.

- ❑ Minimise clearing and unnecessary damage to vegetation (e.g. preferred trimming practices).
- ❑ Maintain canopy connectivity.
- ❑ Minimise sediment washing into waterways.
- ❑ Minimise noise, dust and light.
- ❑ Avoid disturbance to sensitive or significant areas (eg. cultural heritage; rare plants).
- ❑ Seek expert advice on managing vegetation in the WTWHA.

<u>Example</u>: The required trimming practice involves manual trimming of branches that obstruct the safety clearance zone for vehicles (see Section "Roadside Works"). Trimming in the required manner provides a neat-edged cut, which is unlikely to re-sprout (see Figure 3), reducing the need for future trimming. This trimming practice will also encourage canopy connectivity[4], which reduces the "barrier" impact of roads to fauna and provides enhanced visual amenity for the road user.

3.3.2 *Rehabilitate Disturbed Areas*

The Code provides instruction on the following techniques for rehabilitating disturbed areas.

- ❑ Stabilise embankments to prevent erosion.
- ❑ Promote the growth of native plants.
- ❑ Seek expert advice on how to rehabilitate areas of the WTWHA.

<u>Example</u>: Appendix B "Guidelines for Rehabilitation of Disturbed Areas" of the Code was developed in consultation with vegetation and land management specialists. It provides users with descriptions of land stabilising and revegetation methods, including pros & cons and specific applications for using these methods in the WTWHA. Vegetation species lists are also provided for lowland forest areas (0-400m above sea level (asl)); upland rainforest areas (400-800m asl); highland rainforest areas (800+ m asl); Eucalypt & other forest areas. Expert advice also provides examples of some grass species historically used that are inappropriate.

3.3.3 *Maintain Fauna Corridors and Habitat*

The Code provides instruction on the following techniques for maintaining fauna corridors and habitat.

- ❑ Maintain canopy connectivity (e.g. special trimming practices).
- ❑ Minimise sediment washing into waterways.
- ❑ Seek expert advice about fauna crossings and avoiding habitats of the WTWHA.

<u>Example</u>: To reduce the impact of sediment loads in waterways, and the subsequent detriment of aquatic plants and animals, several requirements were developed as follows.

- ❑ Bank stabilisation.
- ❑ Cleaning culverts and check dams prior to excessive sediment build-up (see Section 3.1.3 and Figure 7).
- ❑ Manual cleaning of table drains.
- ❑ Regular maintenance of batter shutes.
- ❑ Sandbagging areas when installing new devices such as fences (see Section 3.1.4).

---

[4] It was initially suggested that canopy connectivity be ensured for a 100m section of every kilometre of road in the WTWHA. This would provide a compromise between the need for fauna passage and opportunity for moisture on roads to evaporate. As minimal areas for potential canopy connectivity currently exist, it was resolved to simply encourage wherever possible.

3.3.4 *Prevent Contamination*

The Code provides instruction on the following techniques for preventing contamination.

- ❑ Manage waste.
- ❑ Contain chemicals.
- ❑ Use correct chemicals.
- ❑ Clean up small spills.
- ❑ Contact specialists in the event of large spills.

Example: Containing chemicals is most important in the WTWHA, however the Code acknowledges that accidental spills may occur. In particular, the Code provides step-by-step instructions on how to prevent spread of contamination by cleaning up spills to land (ie excavation and removal) and water (ie soaking or scraping). Emergency contacts are also provided.

3.3.5 *Prevent Weed Spread*

The Code provides instruction on the following techniques for preventing weed spread.

- ❑ Avoid the introduction of weeds in materials (e.g. fill or mulch).
- ❑ Treat weeds with appropriate chemicals (e.g. non-residuals).
- ❑ Avoid spreading weed seeds/cuttings caught on vehicles or equipment (e.g. washdown).
- ❑ Seek expert advice on weed treatment.

Example: Managing weeds will reduce unnatural competition of native fauna and flora. The Code requires that any vehicle or machinery that enters weedy areas during maintenance will require thorough wash-down in an appropriate facility (see Figure 3). This will ensure weed seeds and cuttings are not spread to other areas within the WTWHA. The Code also provides advice on serious weeds of the WTWHA, and what to do if these are observed. Chemical treatment of weeds must be undertaken with non-residual herbicides, which are safer for aquatic fauna species.

3.3.6 *Minimise Visual Impact*

The Code provides instruction on the following techniques for minimising visual impact.

- ❑ Manage graffiti.
- ❑ Remove waste and tidy site.
- ❑ Consider visual impacts of new features (e.g fences).

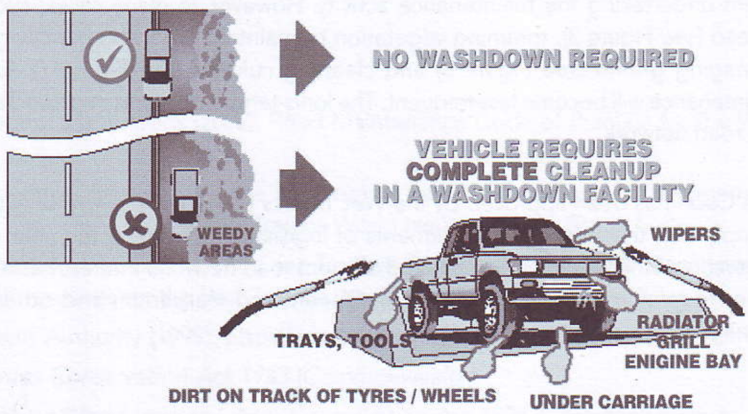


Figure 3: Preventing Weed Spread
(Source: Queensland Department of Main Roads, 2002)

Example: Large Boulders of the WTWHA provide adequate space for graffiti vandals. Cleaning graffiti provides for visual amenity of the WTWHA. However, previous cleaning methods using high pressure hoses have historically provided new, clean areas for repeat graffiti. The Code provides a method of removing graffiti that also encourages the regrowth of lichens, deterring the repeat acts of graffiti (see Figure 6).

3.3.7 *Deal with Emergencies to Prevent Further Harm*

The Code provides instruction on the following techniques for dealing with emergencies.

- Manage landslips, contaminant spills and fallen trees correctly.
- Seek expert advice on emergency management.

Example: Landslips are common in the WTWHA due to steep areas, high rainfall and soil conditions. The Code acknowledges that slips on road cuttings need to be rectified quickly to ensure road access is maintained. However, this urgency must accommodate removal of spoil material and not permit spoil to be pushed off the road formation. This will prevent further disturbance to vegetation. The Code also provides instruction on how to manage fallen timber to ensure valuable nutrients and habitat features remain within the natural systems of the WTWHA.

3.3.8 *Identify Potential Problems*

The Code provides instruction on how to identify potential issues such as weeds, dieback or new cultural heritage discoveries. Notifying specialists of suspected issues can provide a valuable service for scientific researchers.

Example: Dieback (Phytophthera cinnamomi) causes death of trees and is a serious problem in Australia, including the WTWHA. Appendix E "Dieback Identifiers" of the Code provides the user with simple field indicators that may help determine if dieback is present.

4. CONCLUSION: THE FINAL PRODUCT

The "Road Maintenance Code of Practice for the Wet Tropics World Heritage Area" was developed under consultation with road maintenance engineers and work crews, with input from environmental specialists. The final product is a field guide that demonstrates why and how Main Roads should undertake maintenance activities to minimise adverse environmental effects and opportunities to enhance secondary benefits on this special area.

In some instances, undertaking the Code requirements will increase initial time and effort spent undertaking the maintenance activity. However, in many cases, such as preventing weed spread (see Figure 3), trimming vegetation to maintain canopy connectivity (see Figures 4 and 5), managing graffiti (see Figure 6) and cleaning culverts (see Figure 7), future requirements for maintenance will become less frequent. The long-term outcome is improved efficiency in maintaining the road network.

The Code has been approved by the Wet Tropics Management Authority and assists Main Roads comply with the stringent requirements of legislation governing the area; achieve environmental protection; while providing a safe and efficient road network. Interest has also been received from other federal and state agencies, the Queensland Herbarium and other World Heritage Area managers.

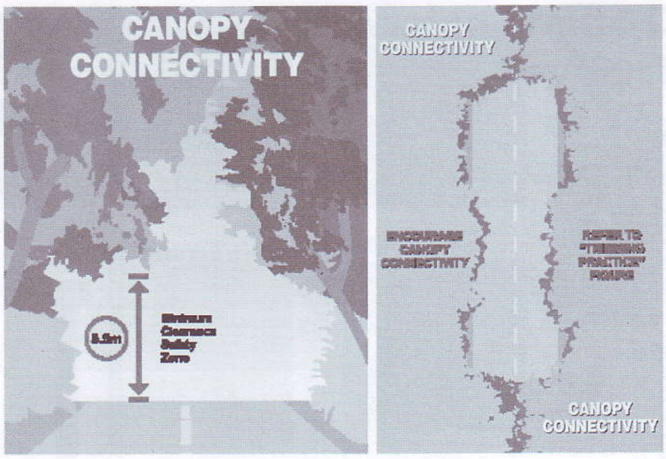


Figure 4: Maintain Canopy Connectivity
(Source: Queensland Department of Main Roads, 2002)

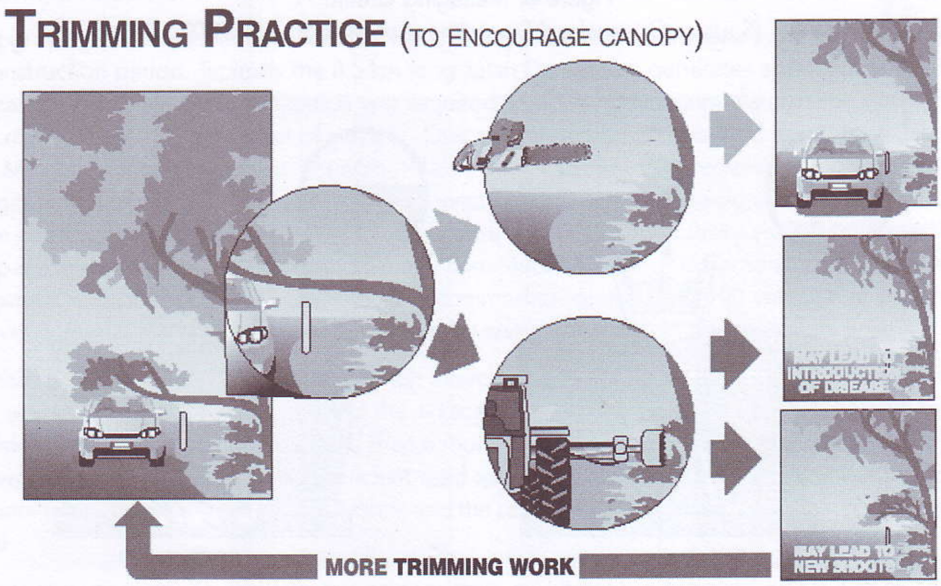


Figure 5: Trimming to Encourage Canopy Connectivity
(Source: Queensland Department of Main Roads, 2002)

The unique process of developing the code was mainly attributed to the stringent management requirements in place for this special area. The attempt to bridge the gap between routine road maintenance activities and stringent environmental requirements may not have been attempted otherwise. The ongoing application of the "Road Maintenance Code of Practice for the Wet Tropics World Heritage Area" indicates that the process in developing the Code may have broad scale application.

REFERENCES

Queensland Department of Main Roads (2002). Road Maintenance Code of Practice for the Wet Tropics World Heritage Area.

Rainforest CRC: Co-operative Research Centre for Tropical Rainforest Ecology & Management (1998). Impacts of Roads and Powerlines on the Wet Tropics World Heritage Area: Stage I.

Rainforest CRC: Co-operative Research Centre for Tropical Rainforest Ecology & Management (2000). Impacts of Roads and Powerlines on the Wet Tropics World Heritage Area: Stage II.

Wet Tropics Management Authority (1999): http://www.wettropics.gov.au

World Heritage Properties Conservation Act 1983 (Commonwealth).

Wet Tropics of Queensland World Heritage Area Conservation Act 1994 (Commonwealth).

Wet Tropics World Heritage Protection and Management Act 1993 (Queensland).

Wet Tropics Management Plan 1998.

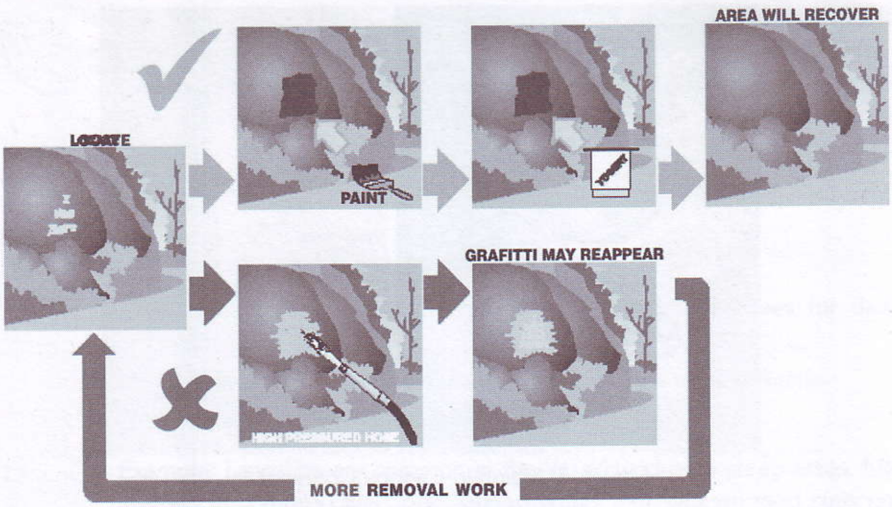


Figure 6: Managing Graffiti
(Source: Queensland Department of Main Roads, 2002)

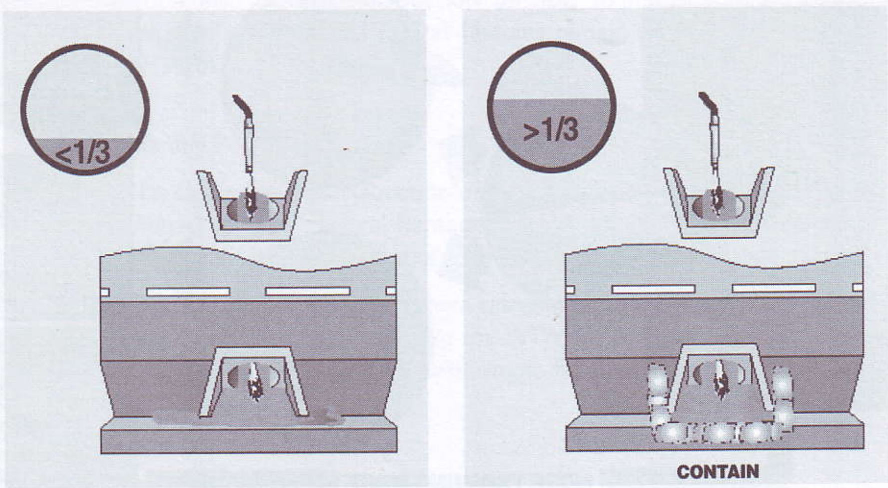


Figure 7: Maintaining culverts to protect waterways of the WTWHA
(Source: Queensland Department of Main Roads, 2002)

ACKNOWLEDGEMENTS

This paper was originally published in the Proceedings of the 21stARRB/11th REAAA Conference, cairns, Australia, May 2003 (ARRB Transport Research Ltd).

The author of this paper wishes to acknowledge the valuable input into the development of the "Road Maintenance Code of Practice for the Wet Tropics World Heritage Area" from the following organisations:

- Wet Tropics Management Authority
- Queensland Department of Main Roads, North Queensland Region
- Queensland Department of Main Roads, RoadTek
- Queensland Department of Main Roads, Road System & Engineering Group
- Queensland Parks and Wildlife Services, Centre for Tropical Rehabilitation
- Queensland Environmental Protection Agency, North Queensland Region
- Rainforest CRC: Co-operative Research Centre for Tropical Ecology & Management
- Queensland Department of Natural Resources & Mines
- Revegetation Contractors Pty Ltd

The Challenges of Managing Traffic During Construction for the One-Way System Maarof-Semantan Interchange of Western Kuala Lumpur Traffic Dispersal Scheme Project

Ir. Md. Shukor Mohamed
Malaysian Highway Authority, Malaysia
Ir. Yeoh Hin Kok, Gamuda Berhad

ABSTRACT

The WTDS project is an important road system, which provides the necessary dispersion of traffic in the western part of Kuala Lumpur. It consists of a new orbital route to complement the Middle Ring Road 1 and 2, a new radial link and the upgrading of an existing radial link (namely Jalan Damansara).

The upgrading and improvement works on the existing Jalan Damansara dealt with life traffic throughout the construction period. Typically the 8.5 km long Jalan Damansara generates about 165,000 veh/day. As such careful planning and coordination was required to achieve minimum disturbance to the road user whilst maintaining the same level of service. One critical section on this road namely the Jalan Johar - Jalan Maarof junction and Jalan Beringin - Jalan Semantan junction requires a more complex traffic management planning than the rest as this two junction (with 3 or 4 phase signalisation) will be upgraded into an interchange and they are less than 1 kilometre apart. The complexity arises as this road traverses an upper class elite residential areas and a major commercial area, the Damansara City Centre (DCC). The DCC when fully developed will be able to accommodate more than 7900 vehicles of parking space. However currently the area is partially occupied by some office blocks and shop lots only.

The initial proposal of constructing a multi-tier interchange at the Jalan Johar - Jalan Maarof junction will cause a nightmare to the road user and the adjacent residence. As an example certain routes/turning movements need to be closed for more than 6 months causing major disruptions to the traffic that may inconvenience the public, there is insufficient road space (constraint by residential properties) to provide adequate temporary lanes for traffic diversion, and the public may have to endure with a longer construction period.

As a counter measures to mitigate this arising issue, an alternative proposal was made to convert the current two-way traffic flow surrounding the DCC i.e. along Jalan Johar - Jalan Beringin - Jalan Semantan and Jalan Damansara - Jalan Semantan into a one-way traffic system forming one big single roundabout. With this new one-way system, two flyovers at Jalan Johar - Jalan Maarof junction and one flyover at Jalan Beringin - Jalan Semantan junction would be built in place of the earlier proposed multi-tier interchange. This new traffic system would provide for a free-flow routing between the mainline traffic flow and the DCC traffic including its future development and at the same time segregating the local traffic movement. The realisation of this new one-way traffic system involved 4 stages of traffic management during construction that will follow through until construction works completed which will be described in this paper. This new one-way traffic system provides more construction space that eases construction complexity with better managed traffic system that increases capacity of the road system by two fold once completed and will be able to cater for future development of DCC.

1 INTRODUCTION

The Western Traffic Dispersal Scheme project (WTDS) is an important road system, which provides the necessary dispersion of traffic in the western side of Kuala Lumpur. Typically one of the radial movements Jalan Damansara generates 165,000 veh/day. WTDS consists of a new orbital route to complement Kuala Lumpur Middle Ring Road 1 and 2, one new radial link and the upgrading of existing radial link (Jalan Damansara).

The upgrading and improvement works on the existing Jalan Damansara (from Jalan Maarof junction to Jalan Semantan) and along Jalan Johar, Jalan Beringin, Jalan Semantan (hereinafter referred to as the loop) and within Damansara City Centre.. This paper will highlight the benefits and limitations of the existing two-way traffic scheme versus the proposed one-way traffic scheme, the challenges of managing traffic during construction for the one-way scheme and the various stages of traffic diversions.

2 LIMITATIONS OF THE EXISTING TWO-WAY SCHEME

2.1 Current Road and Traffic Scenario

The existing traffic flow around the loop is a two-way traffic with 3 or 4 phase junctions at the 4 corners of the loop in order to cater for the traffic movements in this upper class elite residential areas and a major commercial area. Typically part of the 8.5 km Jalan Damansara forms the eastern perimeter of the loop, generates about 165,000 veh/day while on the southern perimeter of the loop is Jalan Johar/Maarof, generates about 44,000 veh/day.

Within this loop, there is a new large development namely Damansara City Centre (DCC). It has a gross site equivalent to 88 stories Petronas Twin Tower high building combined with 2 other towers with a combined 70 stories high building. It is about 2.75 times larger than the current Damansara City Centre (DCC) within the loop. The development has proposed a parking space of 7,900 vehicles. However, currently the area is partially occupied by some office block and a commercial complex.

2.2 Proposed Upgrading of Two Major Junctions And Its Limitations

In view of the current congested traffic flow, Junctions at J1 and J2 require more complex traffic management planning than the rest as these two junctions will be upgraded into an interchange and they are less than 1.0 kilometre apart. At J1, there is a proposed multi-tier interchange construction at Jalan Maarof junction while at J2 is a fly-over construction at Jalan Semantan junction along the congested Jalan Damansara and maintaining dual three/two carriageway traffic movements in both ways along mainline Jalan Damansara. However there are two aspects of limitations to the above proposal as highlighted below.

1. Limitations to the two-way scheme in view of future development traffic within the loop are as follows:
   i. Less able to serve total future DCC developments as expansion of existing road widths and network are limited by the existing road reserves. Further improvements to the multi-tier interchange at J1 is almost impossible as the ramps will be on the fourth level and to ramp down to ground level will require long approaches which will cut-off at grade junctions along the way. The improvement at J1 alone will not provide good accessibility into the new development and will be restrained by the capacity of local access roads with the numerous signalised junctions surrounding the DCC.
   ii. As a consequent from the DCC, the development traffic will further aggravate the commute of local residents due to the restrained accessibility into the development.
   iii. Future access connections from within DCC to the mainline flow and vice-versa are limited as the corridor of Jalan Semantan is already tight with no provision for auxiliary/segregated lane along the dual three mainline.
   iv. Accesses to future developments within DCC will be from Jalan Beringin where the existing signalised junctions are located.
   v. The introduction of future developments of this size will change the road hierarchy of Jalan Beringin from current local access road to one that is of arterial.

2. The limitations of the two-way scheme in view of the traffic management within the loop are as follows:
   i. The existing road reserves have been fully utilised as such unable to provide equivalent temporary number of lanes as well as adequate lane widths to maintain the existing lane capacity and level of service during traffic management.
   ii. During the construction of the Maarof-Johar Flyover, Jalan Johar and Maarof have to be closed for 6 to 9 months to construct the abutments and piers of the fly-over. Traffic has to be rerouted through residential areas.
   iii. During the construction of Semantan Flyover, part of Jalan Beringin connecting to Jalan Semantan has to be closed and mainline traffic diverted via Jalan Beringin and commercial hub of Damansara Heights.
   iv. Encroachment into residential properties is unavoidable due to proximity of structures to property boundaries.

v. As there are large volume of structural works and the requirement for complex temporary works including messy and more traffic management phasing, the construction period requires additional 6 months.

vi. The issue of public outcry due to foreseeable worse traffic jams as a direct result of the above reasons will become paramount and may reach high levels of protest from the upper elite class residents.

3 THE PROPOSED ONE-WAY SCHEME

In order to mitigate the arising issues in the two-way scheme, a proposal to convert the two-way traffic to one-way traffic scheme comes about. This proposal opens up more lanes for construction as the opposite direction traffic lanes can be used for as temporary traffic lanes during construction as well as increasing lane capacity of the highway by nearly two fold. It provides sufficient construction space whilst maintaining the existing traffic capacity.

The one-way scheme consist of two flyovers at Jalan Maarof/Johar junction labelled as J1 and one flyover at Jalan Beringin junction labelled as J3.. The one-way scheme will have a free-flow routing for the mainline traffic while local traffic will be either free-flow or passing through reduced number of signalised junctions.

3.1 Benefits of The Proposed One-Way Scheme

There two aspects of benefits associated with this proposal as highlighted below.

1. The benefits of the one-way scheme in view of the future development traffic within the loop are as follows:
   - i. Future access connection will be flexible and not be constrained by the interchanges as the flyovers are at second level.
   - ii. More lanes can be provided to serve the DCC in addition to the requirement of the mainline and also the segregated service lane can be provided for local traffic along Jalan Beringin.
   - iii. Additional auxiliary lanes can be added for access into and out of the DCC.
   - iv. The Jalan Johar and Jalan Beringin have been upgraded to highway standards in order to cater for future development traffic generated from DCC.

2. The benefits of the one-way scheme in view of the traffic management within the loop are as follows and depicted in the traffic management plans described in later sections:
   - i The construction of the flyover at junction J3 and widening of Jalan Johar and Jalan Beringin can be carried out first before implementing the one-way scheme for the mainline flow during construction of the flyover at junction J1.Traffic disruption can be kept to the minimum. Most of the structural works are out of the present carriageway except for the simple flyover at J1, which will be constructed after implementing the one-way scheme.
   - ii None of the traffic movements need to be closed during construction. All traffic movements can be catered for and still maintaining the same lane capacity as per existing capacity during construction.
   - iii During construction of the approaches for Jalan Beringin Flyover at J3, 3 traffic lanes are provided for mainline plus 2 auxiliary lanes provided for local turning traffic since the constructed reinforced wall for the at grade roads has been completed.
   - iv As for flyover at J1, after implementation of one-way scheme, the traffic is diverted to the adjacent of the proposed flyover approaches and maintaining 3 lanes of mainline traffic and 2 auxiliary lanes for turning movements.
   - v Reduced encroachment into residential properties as the structures are well away from the boundary properties.
   - vi As the volume of structural works is less than the two-way scheme and the flyovers are straightforward construction coupled with streamlined traffic management with much less interfacing, the construction period can be shortened by 6 months.

vii The issue of public outcry has been minimised to solvable levels by having constant rapport with the public and taking into consideration concerns raised.

4 COMPARATIVE STUDIES OF THE TWO-WAY AND ONE-WAY SCHEME

4.1 Traffic Routings

Both the two-way and one-way schemes offer free flow traffic routing on the mainline between Kuala Lumpur and Petaling Jaya. In addition the one-way scheme provides more free flow routes as follows:

1. Providing free flow routing between the mainline traffic and DCC traffic including its future developments.
2. Allows for smooth traffic flow into adjacent areas, such as Bukit Damansara, either on free flow or with a routing with reduced number of signalised junctions to pass through.
3. Reduction of signal phasing at several signalised junctions.
4. Additional capacity due to reduction in signal phasing for the critical movements.

As an example, taking one of the major designated route, e.g. from Kuala Lumpur to 8 other destinations in this loop, 6 out of 8 routes are free-flow with the rest having to pass through either 2 or 3 phase signals as opposing to two-way scheme where all 8 routes require 3 or 4 phase signals with 3 routes having combination of 2 and 3 junctions with 3 or 4 signal phases.

Other major designated routes generally offers 60 to 70 % of the designated routes as free flow routes as compared to two-way scheme which offers zero free flow routes.

4.2 Capacity of Signalised Junctions

Given that the signal phasing of the junctions has been reduced, the capacity of the junctions has increased proportionately resulting in reduction of travel time (see Tables 1 and 2).

As example, to calculate the travel time for the longer route with the assumption of an average delay time of 15 seconds to 45 seconds for 2 phased to 4 phased signalised junctions and a travelling speed of 50 km/h, in general the findings is that the overall travel time is reduced by 10 to 150 seconds whilst the delayed is only 12 seconds for two routings.

With the reduction in signal phasing of the junctions and travel time, the green time to each phase of the cycle time per junction has been significantly increased.

Table 1: Traffic Routing From KL

Destination	C.A. Scheme	One-Way Scheme
To BD1	J3 (3 Phase Signal) & J4 (4 Phase Signal) & J5 (4 Phase Signal)	Free Flow
To BD2	J3 (3 Phase Signal) & J4 (4 Phase Signal) & J5 (4 Phase Signal)	J5 (3 Phase Signal)
To BD3	J3 (3 Phase Signal) & J4 (4 Phase Signal)	Free Flow
To BD4	J3 (3 Phase Signal)	J3 (2 Phase Signal)
To PBD1	J3 (3 Phase Signal)	free flow
To PBD2	Free Flow	free flow
To Maarof	Free Flow	free flow
To PJ	Free Flow	free flow

Table 2: Traffic Routing From KL

Destination	Existing Scheme	One-Way Scheme
To BD1 (Beringin West)	J2 (2 Phase Signal) & J3 (3 Phase Signal) & J4 (4 Phase Signal) & J5 (4 Phase Signal)	Free Flow longer by 750 m faster by 81 seconds
To BD2 (Setiabudi)	J2 (2 Phase Signal) & J3 (3 Phase Signal) & J4 (4 Phase Signal) & J5 (4 Phase Signal)	J5 (3 Phase Signal) longer by 750 m faster by 51 seconds
To BD3 (Batai)	J2 (2 Phase Signal) & J3 (3 Phase Signal) & J4 (4 Phase Signal)	Free Flow longer by 1100 m faster by 10 seconds
To BD4 (Beringin North)	J2 (2 Phase Signal) & J3 (3 Phase Signal)	J3 (2 Phase Signal) faster by 30 seconds
To Maarof	Free Flow	Free Flow

For example, at the Jalan Johar/Jalan Maarof junction, presently the Petaling Jaya to Maarof movement receives 45 seconds green time or 22% of the total 205 seconds cycle time. For 2-phased junction in the One-way scheme with removal of total conflicting movements to flyovers or re-routes etc, the movement can receive over 50 % green time. Furthermore, if the cycle time is reduced, this green time will appear more frequently and the overall queue delay will be reduced.

Generally, the capacity of the signalised junction is increased while the waiting time is reduced with the reduction in the number of phases within each cycle.

5 IMPLEMENTATION OF THE ONE-WAY SCHEME

5.1 Governing Factors Affecting Traffic Management

There are many factors affecting the traffic management and careful planning with effective coordination is paramount to achieve minimum disturbance to the road users whilst maintaining the same level of service. The two main governing factors and the arising issues are being addressed below.

1. The external governing factors are:

   i Life traffic with a volume of 165,000 veh/day. A well-planned traffic friendly Traffic Management is paramount to the success of this project. Detailed 4 stage Traffic Management has been tabled to handle this volume of traffic. Lane provisions of 3 to 5 lanes temporary/permanent are prepared to cater for the demands of traffic. Temporary two-phased traffic lights are installed at location of future junctions to control traffic.

   ii Public awareness and acceptance of the one-way scheme. A number of meetings have been arranged with the various resident associations to explain the rationale and the new circulation of the one-way scheme. The impacts and the routings are discussed closely with them in order to better understand their daily routine and paths taken so that modification to the proposed routings can be carried out to accommodate their requirements as far as possible. Media notifications and pamphlets are frequently distributed to the residents in this vicinity.

   iii Handling of public complaints is important to decelerate and placate the public sentiments. One such organisation, Damansara Heights Residents Pro-Tem Committee headed by influential personnel did result in protest against the one-way system. However, through proper discussions and meetings together with authorities, the committee finally relented to the scheme but with some modifications to ally their concerns. Attached are newspaper clippings to illustrate the extent of the protests.

iv Design changes to accommodate public views/government agencies. Where there are foreseeable design inadequacies or improvement, initiative on our side to better design to cater for comments from residents and local authorities. A dedicated design team on site to handle such changes, working at the same platform with the construction team so that design change can be quickly implemented on site with no delay to the sequence of construction and disruption to the traffic.

2. The construction and technical governing factors are:

i Catering for all existing traffic movements in the Traffic Management Plan and stage out sequence of construction in line with existing traffic flow pattern. Traffic determines the sequencing of works.

ii Unknown numerous existing utilities found under existing pavement as this is the only main trunk road to town and serving a large upper class residents and commercial centre. The related works need to be accurately coordinated amongst the various specialists who are able to resolve any arising issues in relation to technical, sequencing of construction, approval from local authorities and cost. Such coordination is necessary so that the works on site can be carried out swiftly and any works infringing into the traffic road pavement need to be completed within the night such that the road can be paved for the traffic to use the next morning. With this approach, traffic flow is not affected and there is no unduly local "bulging-out" effect of the delineators to accommodate local works, which frequently slows down traffic, and create domino effect of queues forming.

iii In order to reduce disruptions to the traffic, logistics of delivery of construction materials are based on "just-in-time" approached i.e. material is only made available when construction for a particular activity starts. This is to reduce stockpile on site and remove unnecessary sight obstruction to road users as the corridor of construction is tight and turning radius is small. Most deliveries are carried out at night.

iv In order to reduce disruptions to the traffic due to physical obstructions within the roadway, there are Traffic Rapid Response Teams on site to remove stalled vehicles or incidents of accidents so that the traffic flow is not unduly interrupted. Also, where there are accidental debris or alignment of delineators have been shifted due to movements of construction equipment or being hit by commuters, the team will ensure smooth traffic flows.

v The noise and dust pollution level generated by traffic being diverted by the one-way scheme has increased markedly due to proximity of resident properties. Mitigation measures as per Department of Environment will be carried to reduce the impacts. Noise barriers are quickly erected to shield affected residents and there are water tankers on stand by to wet the roadways to reduce dust pollution.

vi To ensure safety of pedestrians crossing the mainline during construction requires careful consideration of signs and adequate warning to motorist coupled with proper pedestrian crossings both elevated and at grade.

With the above factors mentioned, the detail Traffic Management Plan is formulated carefully and is described in the next section of this paper.

6 TRAFFIC MANAGEMENT DURING CONSTRUCTION

The Traffic Management Plan identifies 4 stages of diversion and it will be conducted along Jalan Damansara from Jalan Maarof Junction to Jalan Semantan Junction, and along Jalan Johar, Jalan Beringin, Jalan Semantan and within DCC to facilitate the widening works, trees and services relocation, and the construction of fly-over.

With the implementation of One-Way Scheme, the Kuala Lumpur/Petaling Jaya main traffic flow will not be congested by the construction of fly-over at Jalan Damansara/Maarof junction. Wherever possible, traffic will follow the final pattern to minimise confusion to road users when the final stage of diversion is being implemented.

6.1 Traffic Management Stages

6.1.1 *Stage 1*

The following traffic management activities are summarised below:

i All existing traffic movement to be maintained.

ii Localised lane closure during construction (night works where necessary).

iii All work zone adjacent to public traffic to be delineated using plastic barrier.

iv Temporary diversion road signs adjacent to work site to be erected as per plan. Mini VMS are located at strategic locations to ensure visibility at night.

v Roads need to be lighted at night or alternatively blinkers to be provided at 20m.

vi The colour scheme for all temporary traffic signs shown shall be as per authorities requirements.

The associated construction activities corresponding to the above stage traffic diversion are as follows:

i Existing medians along Jalan Johar, Jalan Beringin, Jalan Semantan & Jalan Damansara to be excavated and paved to form part of the permanent carriageway.

ii Traffic islands at Jalan Damansara-Johar, Jalan Johar-Damanlela, Jalan Johar-Beringin, Jalan Beringin-Damanlela and Jalan Semantan-Damansara junctions to be removed and paved for the 3 lanes one -way traffic.

iii Slip road from Jalan Damansara (PJ bound) to Jalan Maarof CH E +0 to E+600.

iv Slip roads 12K, 12Q, 12R, 12S, 12T & 12V (at Jalan Beringin).

v Existing street lightings and landscapes at the above areas to be relocated.

vi Temporary 2 phase traffic lights to be installed at JB +1040.

6.1.2 *Stage 2*

This stage involves the implementation of the one-way traffic diversion scheme. The following traffic management activities are summarised below:

i Traffic from Petaling Jaya (PJ) to Kuala Lumpur (KL) will be diverted through Jalan Johar to Jalan Beringin to Jalan Semantan.

ii Traffic from KL to PJ maintains existing flow pattern.

iii Traffic lights at Jalan Beringin-Damanlela, Jalan Beringin-Semantan and Jalan Semantan-Damansara junctions to be disabled.

iv Traffic from Jalan Batai/Damansara Heights to PJ/Maarof via Jalan Beringin to Jalan Semantan to Jalan Damansara. A temporary 2 phase traffic lights will be provided at JB +1040 to allow PJ/Maarof bound traffic from Jalan Semantan taking right-turn into Jalan Damansara.

v Traffic lights at Maarof junction to be reduced to 2 phases i.e. from KL to PJ and from PJ to Jalan Maarof. Traffic from Jalan Maarof to Johar will be diverted to a free-flow U - turn provided at Jalan Damansara/Bukit Kiara Junction (I/C No. 10), the next interchange on the downstream.

vi Traffic lights at Jalan Johar-Setiabudi to be reduced to 2 phase at the same time maintain free flow for Johar-Beringin main traffic.

The associated construction activities corresponding to the above stage traffic diversion are as follows:

i Maarof Fly-over.

ii Semantan Fly-over and approach walls.

iii Slip road from Jalan Maarof to Jalan Damansara (PJ bound) CH B+0 to B+350.

iv Jalan Johar-Damansara slip road.

6.1.3 *Stage 3*

The following traffic management activities are summarised below:

i PJ bound traffic from KL diverted to Jalan Damansara RHS slip road for the approach walls construction.

The associated construction activities corresponding to the above stage traffic diversion are as follows:

i Maarof Fly-over and approach walls.

ii Semantan Fly-over and approach walls.

iii Jalan Damansara -Johar slip road.

iv Jalan Johar- Beringin slip road.

v DCC slip road F&G.

6.1.4 *Stage 4*

The following traffic management activities are summarised below:

i Traffic is diverted onto newly constructed fly-over.

The associated construction activities corresponding to the above stage traffic diversion are as follows:

i Construction of slip roads underneath the Maarof and Semantan fly-overs.

ii During the 4 stages of traffic diversions, constant monitoring of public complaints is being carried out in order to ensure that any additional movements can be catered for and there is no undue congestion caused by any obstructions. Traffic marshals are on stand by to attend to any accidents or congestions.

7 CONCLUSION

The implementation of the one-way scheme has generally increased the capacity of the current road network within the loop. The one-way scheme proposal was initially met with a lot of resistance from the resident associations but eventually after much clarification it was accepted and currently functioning effectively in dispersing traffic within the loop. The implementation of the traffic management has successfully mitigate public concerns and also providing an acceptable level of service as well as shortening the whole construction period within the loop by 6 months.

8 ACKNOWLEDGEMENTS

This paper was originally published in the Proceedings of the 21st ARRB/11th REAAA Conference, cairns, Australia, May 2003 (ARRB Transport Research Ltd).

The authors wish to thank the management of Malaysian Highway Authority for allowing this paper to be presented.

Toward An Integrated Management System In Road Construction In Brunei Darussalam

Dr Yong Chee Tuan, Chong Fong Sien and Rafitra H. A. Razak

ABSTRACT

In Brunei Darussalam, Environmental Impact Assessment (EIA) is not mandatory even for major road construction or infrastructure development. However, some forms of impact assessments are often available as part of the feasibility studies for many of these projects. These exercises focus primarily on the merits and problems arising from the changes in the physical environment. The socio-economic changes and impacts are often being played down. Modern transportation planning cannot ignore the whole spectrum of the environmental impacts that occur during construction, operational and maintenance phases. This paper introduces the concept of an integrated management system that would help key organisations to enhance the existing engineering practices. The paper discusses all the three components namely Health and Safety, Environmental and Quality, in relation to the challenges and opportunities in the change process. Subsequently, the paper provides a case for Brunei Darussalam's road construction industry to become more responsible, competitive and relevant in the increasingly globalised economy.

1. INTRODUCTION

Infrastructure development such as road construction has brought about many benefits to the urban dweller. Among these benefits are better transportation, and accessibility to other amenities that in the last few decades were only available to a few privileged people.

However, there is increasing concern with regard to the health and safety of the people who are now enjoying these new facilities. Recent air pollution studies in some of the Association of South-East Asian Nations (ASEAN) countries have indicated a steady increase in air particulate, smog, nitrogen oxides and in many other asthmatic-related pollutants. Water quality studies on rivers are similarly gloomy; heavy metal and hydrocarbon content is increasing.

The rapid pace of infrastructure development in many of the South-East Asian countries coupled with the steady growth of the construction and manufacturing industries, has introduced a cause for several environmental concerns. The city dwellers' concern for their health and safety due to environmental degradation (such as air and water pollution), failures of structures (such as building collapses), and natural events, (such as floods and landslides), are included in these environmental issues. Even these natural events are not entirely without the influence of human activities that have added to the damaging consequences.

This paper reflects on the connection between the desired sustainable development in Brunei Darussalam and the organisations involved in road construction. It focuses on the emerging concept of good governance through the integration of a Health, Safety, Environmental and Quality (HSEQ) system into the overall culture. This structural change within an organisation can help to provide solutions supporting development strategies by proactively improving the environmental quality while minimising any negative impact on the environment.

Development is often interpreted as a series of economic activities that will induce physical changes to the environment and demand some forms of social adjustments. The widely quoted definition of sustainable development as derived by the World Commission on Environment and Development (1987) is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

In other words, these activities can only be called sustainable development if their subsequent changes and adjustments will progressively improve living conditions, promote biodiversity, conserve natural resources, and minimise hazards. Unfortunately, many of the current development activities do not always satisfy all of these conditions. In most cases, both the environmental conditions and the health and safety of the dwellers are neglected amidst the overall benefits of the project.

The complexity of development is made worse by the need to provide a proper health and safety system on the construction sites, and to protect the operators, users and neighbours of the finished

projects. The damaging effects extend from nearby to the wider environment. It is not difficult to imagine that these 'improvements' are like the 'quick fix' solutions that do not last long as soon as the effects of the degraded environment become too much to be comfortably ignored. Therefore, attempts to assess such widespread and lingering impacts resulting from a particular development activity, such as road construction, have always been unsuccessful. As a result, this means that no single organisation can be solely blamed for the kaleidoscope of problems.

2. ROAD CONSTRUCTION AND ENVIRONMENTAL IMPACT ASSESSMENT

Many people in the construction industry are very familiar with some of the impacts of their development projects. Such positive and/or negative impacts are even more pronounced in the case of a major road construction. However, it is not uncommon to find a vast variation of perceptions and ideas of the development among the developers and supporters, and the many stakeholders, such as the local community, neighbours, NGOs and the local authority.

Naturally, the most direct and immediate benefits to, or adverse effects on, the individual group will govern how it is generally perceived and the value of the development. While the whole spectrum of any impact is yet to be established, the concerns of the more active or vocal groups are often recognised and taken into consideration at an early stage. This syndrome is common in many countries where there are legislative or mandatory requirements for conducting an environmental impact assessment (EIA) before starting a major infrastructure development.

'Public consultation' is normally focused on the more active stakeholders. They are usually well represented. They can heavily influence the consultation process even though they might constitute only a minor part of the impacted community. Many positive socio-economic impacts on other groups can often be misunderstood or manipulated to appear as 'insignificantly beneficial' to the overall development of the project. These are biased even further when they are measured against either a marginally or significantly negative change in the physical environment. Coupled with the existing pressures on the local authorities, particularly in developing countries, to appear as more environmentally sensitive and responsible, many meaningful projects are either shelved or undertaken with a somewhat detached commitment from all relevant parties.

A comprehensive understanding and analysis (cost/benefit) of road development is now becoming increasingly difficult to determine, so preventing the careful optimisation which will bring out the maximum benefits of the project. Hence, most of the national visions and hopes, including local and concept plans, are faced with great hindrances and pitfalls during their implementation. Some developed countries are experiencing similar troubles; especially those that have very stringent health, safety and environmental legislation. Potential investors, such as joint ventures and multinational corporations (MNCs), may be discouraged by the fact that the existing infrastructure, including road networks, are not open to negotiation in terms of diversion, or other change, even if they are not providing sufficient strategic advantages. Such harsh measures taken by the local authority seem incompatible with its desire for more foreign direct investment (FDI) and economic growth, on the one hand, and with ensuring a high quality of urban life with environmental protection on the other.

The assessment of the influence of environmental regulation on FDI (Campbell 1992) is inferred from the declining FDI in the manufacturing sector in Australia and New Zealand, taking into account the cost of labour and material, and other economic parameters. EIA is not mandatory before starting any major road construction or infrastructure development in Brunei Darussalam. Nevertheless, some form of impact assessment has been conducted and included as part of the feasibility studies for many projects.

This practice forms the underlying approach and the basic requirement of Chartered or Professional Civil Engineers when performing their duties with serious consideration of health, safety and environment issues. While the professional ethics and integrity of engineers will remain intact, their roles in taking into account these vital issues, in the planning, design or construction stages, do not need to incorporate inputs from other disciplines. Such requirements would encourage most consultants to shift their focus on to the merits and problems of the physical state of the environment. Their clients would then be led to examine and adopt the various engineering solutions with the financial implications proposed by the consultants. Other socio-economic changes that might deserve a similar critical assessment and analysis are sometimes neglected.

3. HSEQ CONCEPT

Of the three components of the HSEQ system-health and safety, environment, and quality compliance-the quality system (as in the ISO 9000: 1994 and the recent ISO 9000: 2000 revised edition) is perhaps the most highly sought after certificate by major companies operating in the region. Those certified companies tend to have a better competitive edge when securing bigger market shares in their respective fields by constantly delivering quality products and gaining customers' confidence. The environmental component (as in the ISO 14001: 1996 Environmental Management Systems), while being similarly crucial in assessing and maintaining the general development progress and the performances of companies in specific, is only slowly being recognised and appreciated regionally. A comprehensive understanding and implementation of health and safety are just surfacing in the public sector, although some MNCs, such as the Brunei Shell Petroleum Co. Sdn. Bhd., have long practised this concept.

It is unrealistic to expect all the involved parties (developers, planners, engineers, contractors and auditors) to become environmentally, socially and technically responsible and committed to moving towards a sustainable development culture without a sound framework of national guidelines and some forms of incentive from the public sector. Developers are usually reluctant to award any contract to a higher bidder, even though they might provide better quality in terms of HSEQ. Many of the obligatory or recommended works have been given the label 'do it next time'. The consequences of these activities are quite serious. The obvious ones are the human-induced accidents due to negligence, bad design and poor quality of construction (methods and materials).

Some of the common accidents that have occurred are structural collapses, road accidents, landslides, and disturbances to services (e.g. HV cables). The less obvious problems include the increase in health costs and the deteriorating health conditions of the workers, users or surrounding residents, probably because of their exposure to some unidentified pollutants. All these may be fine for the time being and until such an accident occurs, but eventually the resulting costs will be shouldered by each of the involved organisations. Some of these costs are:

- payment for compensation and allowances;
- a tarnished image which may create an obstacle to future tender;
- downtime, yield loss, scrap, rework and retest, and reduction in profits;
- additional recruitment and training of new staff may have to be carried out;
- negative staff morale; and
- difficulties with future business collaborations/joint ventures when working with other responsible organisations.

Several distinguished management authorities, such as Deming (1982) and Crosby (1979) have demonstrated that productivity (and so profits) is a by-product of an organisation properly implementing a quality system. Although management strategies have always being identified as culturally oriented, Deming's Quality System (initially developed in the USA) was widely recognised as leading the Japanese quality revolution.

The Japanese began to heed his advice on quality management, including statistical process control for monitoring quality performance, in the 1950s. During the 1980s, concerns about American competitiveness steered many US companies to a new interest in quality (Garvin and March 1991). Crosby was one of the leading consultants who successfully championed and developed the quality concept of zero defects through the high standard of commitment, performance and communication.

Shortly afterwards, the British also began to introduce their own versions of quality management systems; more precisely BS 5750, which was first written in 1979. In 1987, this standard was then harmonised with the International Organisation for Standardisation ISO 9000 series, and later made compatible with the European Standard EN29000. Further refinements in the ISO 9000 series were made in the 1994 versions and were subsequently adopted (completely, except for the differing titles and numbers) by more than 76 countries including all the ASEAN countries.

An intrinsic strength of the ISO 9000 system is the certification by an independent and recognised third-party assessor who maintains surveillance on the certified organisation to assure continued conformity. Thus, the organisation needs to be certified only once to comply with the needs of many customers; this has become more important with the recent increase in awareness as led by the example of several governmental organisations and MNCs who insist that their tenderers should be certified to the ISO 9000 standard. In other words, an organisation that has been awarded the PBD ISO 9001 in Brunei Darussalam will automatically be internationally accepted as a 'quality organisation'.

The opinions regarding the advantages and disadvantages of getting the ISO 9000 certification, as outlined by Clements (1993), are as follows:

Advantages

- an improvement in staff morale and staff motivation (an opportunity to recruit better staff);
- a greater awareness of customer needs and requirements;
- a better control over processes (reduction of waste);
- an ability in securing existing business and an opportunity to compete in new markets; and
- documented procedures allowing better communication, training, and assessment.

Disadvantages

- time consuming, expensive to obtain and maintain;
- can end up to be too bureaucratic and less flexible;
- difficult to fully change attitudes; and
- image may be tarnished if failure to secure registration.

Whatever the reasons are, the success of the ISO 9000 standard has given much impetus to organisations (governmental or non-governmental alike) thinking seriously about an environmental management system. Many developers and MNCs are insisting that their business associates and contractors should have an environmental management system in place (to provide proof of an environmental plan, policy and program). Some of the most recently established environmental management systems are BS 7750: 1994 Environmental Management System, the European Eco-Management and Audit Scheme, and the latest ISO 14001 Environmental Management System (1996).

Since the launch of ISO 14001 in 1996, the standard has been gaining a lot of support and acceptance in the region. The ISO 14001 standard is often perceived as the next logical progression for an organisation that has been certified to ISO 9000 - a sign of continual improvement in the organisation. Each standard has its own system of certification for compliance and a recognisable logo, but they share many similar characteristics and requirements as Welford (1995) briefly summarises.

- Environmental policy and commitment - an organisation needs to demonstrate that its top management is committed to change and improving environmental performance.
- Environmental review - a need to carry out an initial/ baseline study of the system and activities of an organisation.
- Personnel structure - appropriate personnel with proper training across the board are involved in contributing ideas and solutions to improving performances.
- Audits and verification - the organisation must carry out periodic audits of the operations and systems based on a detailed and documented plan.

Within this framework, a few notable companies in the developed countries have promoted strategies for enhancing environmental performance within their organisations (Fitzgerald 1994). Some have even reported financial gains by 'just being green'. Safety is closely connected with the environment, hazardous materials, and damage to the environment (Sadgraove 1992). The provision of 'health and safety' to all (employees, sub-contractors, clients and users) has been called for since 1937 by the International Labour Office (ILOM 1937). Subsequently, in 1988, a revised draft was proposed during the Safety and Health in Construction Convention. It placed greater emphasis on the employers and main contractors to implement measures (in compliance with national conditions and practice) protecting the health of their employees and sub-contractors, respectively. The message was reiterated at the United Nations Conference on Environment and Development (UNCED, Chapter 6: Protection and Promotion of Human Health), where it was suggested that health interacts strongly with social, economic and environmental factors (Grub et al. 1993).

The costs of occupational accidents and illnesses can put a drastic financial burden on an organisation; affecting its competitiveness and, at worst, its ability to stay afloat. Conversely, improvement of the organisation's culture to genuinely provide for a safe and healthy working environment in all its activities (during the construction, maintenance and decommissioning stages) are proven to have positive effects. These include the reduction in lost time injuries, the increase in productivity, and the improvement of staff morale; most of which are not immediately noticeable.

Before ISO comes up with a working draft of a health and safety management system (ISO CD 14690: to be incorporated within the environmental management system), several MNCs have already

developed some form of safety assurance practices. Notably, the Northumberland DuPont's Safety Training Observation Programme (STOP) (which focuses on the role of supervisors to decide, stop, observe, act, and report) and the Shell International HSE Management Systems EP 95-0100 (which targets its exploration and production functions in order to streamline its health, safety and environmental management system). Overall, the basic steps required in establishing a health and safety management system are as follows:

- draw up a safety and health plan and policy;
- plan, identify and assess hazards and risks (such as hazard identification, risk assessment) and programs (for preventive measures and response actions);
- implement control measures;
- monitor and minimise undesirable working hours and conditions;
- administer training and carry out supervision (ensuring safe and proper use of equipment, tools and machinery); and
- record, communicate and document incidents.

4. PLANNING, IMPLEMENTATION AND GENERAL OUTLOOK

Within just four years of launching the PBD ISO 9000 in Brunei Darussalam, about 100 organisations have been certified to either the ISO 9001 or ISO 9002 standards (ISO 2000). Of these organisations, more than 40 per cent are road construction related organisations, (either consultancy or contractors). The Ministry of Development has also indicated that, in the near future, such a requirement may become mandatory for companies who wish to seek a large-scale contract. The engineering divisions of Brunei Liquified Natural Gas (BLNG) Co. and the Brunei Shell Petroleum (BSP) Co. Sdn. Bhd. (the two largest private companies) have both been certified to ISO 9001, indicating that they may also insist their contractors/sub-contractors or associates are similarly competent as far as quality management is concerned.

On the environmental, health and safety issues, Brunei Darussalam has not imposed a penalty structure that will lead the way to fines or jail sentences for 'unsafe' practices. In this respect it is unlike its neighbours which have several stringent national regulations, such as the Singapore Factory Act (1974) and the South Australia Occupational Health, Safety and Welfare Act (1986), governing general construction activities with respect to safety and health. Although these Acts differ in terms of the type of offences, fines and in some other minor details, their coverage, requirements and nature of administration share many common themes.

There are several forms of punishments that will act as deterrents to poor performers in terms of HSEQ aspects. The Public Works Department, as a client, can ban or suspend (normally for a minimum period of six months) a contractor from participating in subsequent tenders. Furthermore, the developers, designers and contractors can be punished under common law for negligence with regard to safety. There are some safety-related documents published by the Ministry of Development, such as PBD12: 1994 - Building Guidelines and Requirements, GD8: Site Safety Auditing, and GD3: Guidelines on Investigation of Accidents. A draft regulation for safety on construction sites is being prepared and finalised by the Committee on Safety.

In order for EIAs and QA to be implemented successfully, there should be a total commitment from all parties involved in the project. These key stakeholders are the public sectors, local authorities, consulting engineers, contractors and suppliers. While the contractors are responsible for completing a project according to the terms, conditions, designs and specifications as documented in the contract document, the direct influence of clients and engineers on the contractor's HSEQ performance cannot be overemphasised. At the outset, the designers should determine and advise the client with regard to the needs and the mode of conducting an EIA; taking into account not only the physical environment, but also the changes in the socio-economic environment.

In Brunei Darussalam, the Public Works Department is normally the client for major road projects. One of their emerging practices is to ensure that sufficient emphasis is placed on the quality, environmental impact, and health and safety of the projects. This is translated into a requirement by consultants or in-house engineers to develop a comprehensive feasibility report that encompasses the HSEQ aspects. Specifically, the tender document will call for contractors to consider environmental impact, and to provide a health, safety and quality plan.

The terms of an EIA should be guided by national visions and aspirations together with relevant local concept plans (Project Implementation Manual, Brunei).

The effect of environment impact of a project is a factor that cannot be ignored. The project team must take into consideration the effect their project will have on the environment before proceeding with the implementation.

However, the contractor is not relieved from providing safety and environmental measures during the implementation stage of the project, as demonstrated by the Ministry of Development's Safety Policy that clearly states that:

'. . . all work shall be carried out on any project with safety as a primary objective, and that all persons engaged in this work shall act positively to prevent injury to themselves or to others . . . and paying full regard to the preservation of the environment.'

In particular, the contractor's commitment to providing HSEQ during a road construction project is more visible to the public than is the case of a building project. This is because most road construction projects (especially the upgrading of existing roads) cannot be fenced in completely from the public. Normally, existing roads need to remain open for public use during the upgrading work. Any excavations need to be clearly marked by warning signs or barricades to prevent passers-by from falling into them. Adequate, proper and efficient road warning signs need to be erected at the strategic locations to warn road users.

In short, contractors have to choose a methodology that is friendly to the environment as well as visible (good communication) to other relevant authorities (e.g. the Police Department). The related technical requirements are often defined in the specification but not listed as an item in the Bill of Quantities. By emphasising good corporate governance and a self-regulatory system, contractors are obliged to provide the necessary health, safety, environmental and quality measures without constantly referring to any specific items or rates in the Bill of Quantities. This also helps to eliminate the disputes over the provision of certain safety and quality items that have not been priced earlier.

Another important aspect of this HSEQ system is the learning mechanism. Feedback and other important communications are transmitted both up and down the party channels. Downward communication means that the information flows from the clients and engineers to the contractors. Upward communication refers to the flow from the contractors to the clients. These communication channels ensure that mistakes are corrected and lessons learnt.

5. DISCUSSION

Perhaps the three most promising strategies for organisations involved directly in infrastructure development activities are:

(a) the promotion of a quality management system – the ISO 9000 series; and

(b) the practice of environmental management systems – BS 7750 and ISO 14000 series;

(c) the provision for occupational health and safety.

In this paper, the three-tier approach as referred to as the Health, Safety, Environmental Quality (HSEQ) system.

Elsewhere in the country, BSP and BLNG have set an example of a proactive health and safety initiative, namely HSE Standard: TMS 0434. These companies will not invite contractors to participate in any of their tenders and activities if they do no have an HSE plan, policy or a visible HSE provision or measure. A successful tenderer cannot mobilise and start work unless it satisfies the Milestone Zero requirements - such as the preparation of safety plans, programs, labour quarters, etc. Here, the signs are pointing towards a 'must have' rather than a 'nice to have' culture of a well-documented system consisting of health, safety and environmental management within an organisation that will secure new market opportunities or even maintain existing status in the twenty-first century.

Despite these promising advantages and the 'win-win' situation (Caincross 1995) for blending sustainable development concepts with increasing profits, there are some hiccups in the implementation of the HSEQ system. One main reason for this is the perception held by some governments that the implementation of a quality standard is helping the MNCs and the developed countries at the expense of the developing countries whose organisations are most likely to be disqualified for their delay or inability to achieve the demanding ISO 9000 standards.

The second reason is the cost impact on the organisations which eventually will be borne by the clients who are still reluctant to award a contract to other than 'the lowest bidder'.

Although, in the long run, the costs of implementing an HSEQ system would be absorbed by the increase in productivity and profits, the immediate cost impact cannot be ignored.

Finally, the lack of technical expertise and a fear of failure to comply with the standards of an 'unfamiliar working culture' remain tough obstacles to overcome when bringing about an HSEQ system.

6. CONCLUSION

Three of the prominent changes discussed in the paper are: firstly, the promotion of quality standards (considerations for delivering quality products); secondly, the practice of an environmental management system (conserving natural resources, protecting the environment); and finally, the provision for health and safety to all (complying with regulations and legislation). There are many indications that these changes will remain and become more significant. The implementation of the proposed three-tier HSEQ system was also discussed along with the anticipated problems. Nevertheless, the final note is to encourage all organisations to move towards the HSEQ system in order to stay competitive in the twenty-first century. A successful implementation of an integrated HSEQ system by all the relevant parties in road construction will inevitably tackle the existing problems of conducting EIAs and providing adequate QA.

REFERENCES

BS 7750: 1994. Environmental Management Systems. BSI, London, UK.

Caincross, F. (1995). A Guide to Business and the Environment. Earthscan Publications, London.

Campbell, D. (1992). Environmental Regulation: Its Impact on Foreign Investment. Graham and Trotman Limited.

Clements, R.B. (1993). Quality Manager's Complete Guide to ISO 9000. Prentice Hall, London.

Crosby, P.B. (1979). Quality is Free. McGraw-Hill, New York.

Deming, W.E. (1982). Quality, Productivity and Competitive Position. Cambridge, MIT, Center for Advanced Engineering Study.

Fitzgerald, C. (1994). Selecting Measures for Corporate Environmental Quality: Examples from Tqem Companies. In Environmental TQM (Willig, J. (Ed.)). 2nd Ed. McGraw- Hill, New York, pp. 165-76.

Garvin, D.A. and March, A. (1991). Harvard Business School Background Note: The Views of Deming, Juran and Crosby, in Unconditional Quality. The Harvard Business Review, pp. 17-29.

GD 8: Issue 1: Site Safety Auditing, Ministry of Development, Brunei Darussalam.

GD 3: Issue 1: Guidelines on Investigation of Accidents, Ministry of Development, Brunei Darussalam.

Grub, M., Koch, M., Thomson, K., Munson, A. and Sullivan, F.T. (1993). The Earth Summit Agreements: A Guide and Assessment. Earthscan Publications, London.

International Labour Office. (1937). Safety Provisions, Building Convention and Recommendation. ISO, Geneva, Switzerland.

ISO 9001: 1994. Quality Systems: Model for Quality Assurance in Design, Development, Production, Installation and Servicing. ISO, Geneva, Switzerland, 2000.

ISO 14001: 1996. Environmental Management Systems,.ISO, Geneva, Switzerland.

ISO 9001: 2000. Quality Management Systems - Requirements. ISO, Geneva, Switzerland.

PBD 12: 1994. Building Guidelines and Requirements, Ministry of Development, Brunei Darussalam.

Sadgraove, K. (1992). The Green Guide to Profitable Management. Gower Publishing.

Welford, R. (1995). Environmental Strategy and Sustainable Development. Routledge, London.

World Commission on Environment and Development (1987). Our Common Future. Oxford University Press.

ACKNOWLEDGMENTS

The paper was presented at "The Regional Seminar on Quality Roads - The Way Forward", October 2-4, 2002, Bandar Seri Begawan, Brunei Darussalam.

Review of Chemical Stabilisation Technologies and Applications for Public Roads in Brunei Darussalam

Hj. Suhaimi Hj Gafar
Ministry of Development, Brunei Darussalam

Dr. Wu Dong Qing
Instek Holding Pte Ltd, Singapore

ABSTRACT

There are a lot of swampy and lowland areas as well as weak soil conditions in Brunei Darussalam. To build up quality public roads over these difficult conditions is the target for the Public Roads Department and professionals. Since 1995, the chemical stabilisation for crusher runs and soils using the cold deep in-place recycling technology of construction has been applied for various road projects over the country and it has been proven to be an effective approach for quality road pavement construction. In this paper, the major projects with the chemical stabilisation in Brunei Darussalam have been reviewed. The benefits and long-term performance of the roads by using the chemical stabilisation technology have also been discussed. The popular-used stabilising agents such as cement and Chemilink SS-111 for crusher runs and Chemilink SS-108 for soils have been introduced with their advantages and application conditions. The further studies on the various pavement designs with different stabilising agents and the stabilised materials are in progress in order to identify better solutions under local conditions for more quality roads. Lastly, the requirements of the quality control for the chemical stabilisation have been highlighted to ensure a proper application of the chemical stabilisation.

1. INTRODUCTION

Brunei Darussalam is the country, sandwiched between the states of Sarawak and Sabah of Malaysia, located in the north west coast of the Borneo Island. With a population of nearly three hundred thousand, Brunei has a total land area of about 5,800 km". Within the land area of Brunei, there are a lot of swampy and low land areas as well as weak soils, which cause difficulties in construction and maintenance of local roads. For example, one of the major issues is the differential settlement that increases the initial construction cost and shortens the maintenance period. For passed years Brunei Public Works Department (PWD) has spent a lot of efforts to try different technologies and products, such as pile foundation, geogrid system and chemical stabilisation in order to find more suitable methods for Brunei public roads.

The history of chemical stabilisation practice in Brunei can be traced back to the early 1950s (G.H. Myles, 1950s). About 50 years ago, Brunei PWD proposed and used soil-cement stabilisation way to build up the sub-base course for heavy traffic roads and the base course for light traffic roads. A mixture of 80% sand and 20% clay was mechanically mixed with about 5.0% to 6.5% (by the dry weight of soils) cement and later some chemical additive was added in order to increase the compressive strength. After satisfactory site trials, Brunei PWD had a good and basic understanding on the chemical stabilisation in major technical and commercial aspects, such as laboratory and field tests, machinery, construction procedure and sequence, quality control and the stabilisation cost. Based on the practice and analyses, Brunei PWD had concluded that the chemical stabilisation might be one of the most satisfactory construction methods over the swampy areas.

Since 1995 Brunei PWD has concentrated on chemical stabilisation with different stabilisation agents for local soils and the imported/local crusher runs. Different site trials with length varied from hundreds meters to few kilometres have been carried out at worse soil conditions or at swampy or low land areas. Numerous types of chemicals in liquid form and a modified cementitious chemical in powder form called Chemilink SS-108 soil stabilising agent have been tried to stabilise the insitu soils as the sub-base course of the roads. In some cases, the surrounding sandy or silty soils were imported either for raising the sub-base elevation or partially for improving the properties of the insitu soils to be stabilised. Several types of chemical stabilisation agents, including Ordinary Portland Cement, polymer-base products such as Polyroad (in powder form) and Renolith (in liquid form and used in junction with cement), the modified polymer cementitious chemical such as Chemilink SS-111 stone

stabilising agent, have been tried to stabilise the in-site or imported crusher runs as the base course of the roads. Chemical stabilisation with Chemilink(Technologies and Products has been found to be one of the more technical and cost effective methods for roads construction, based on the performance and durability of Brunei public roads projects with Chemilink stabilisation, especially for Chemilink SS-108 Soil Stabilisation.

The appropriate stabilisation machinery and the proper construction procedure/sequence are very important for obtaining satisfactory results of chemical stabilisation. It looks difficult without these two factors no matter how good and effective the chemical stabilising agents are. In 1995, Brunei PWD introduced the specialised insitu stabilising/recycling machines and construction techniques commonly called as "the cold deep in-place recycling technique of construction". A mechanical Spreader and a Stabiliser (such as CMI 500B) are essential to achieve the satisfactory stabilisation result, where the motor grader and water truck are needed as assisting machinery. The main stabilising construction steps are necessary, which are "spreading, insitu mixing and compaction".

In addition to the correct and applicable pavement designs including the determination of applied dosage of the used chemical agent for different road cross sections, the insitu and in-house tests on the stabilised mixture layers during and after the stabilisation process can help us assure the stabilisation quality. In July of 1999, Brunei PWD published "General Specification for Pavement Stabilisation" (CPRU, 1999) as an authorised guideline and regulation on stabilisation for road construction. It should be the first authorised specification for pavement stabilisation in the South East Asia and it is also a milestone of stabilisation practice with the professional standards for the road pavement construction in this region. This general specification covers a comprehensive range of pavement stabilisation from materials, equipment; mix design, construction to quality control. The detailed specifications and quality control standards on chemical stabilisation with cement, bitumen and polymer base products for road base and chemical products for sub-grade and sub-base have been provided in this specification.

2. CHEMICAL STABILIZATION AND CONSTRUCTION METHODS

Generally the commonly used soils and gravels for road construction belong to the range of soils. Soil stabilisation with or without admixtures is a practical approach of soil improvement and the chemical stabilisation with numerous chemical-stabilising agents is the most commonly used method of the soil stabilisation. In this chemical stabilisation, one or more chemical compounds are added into soils for treatment through chemical reactions between these chemical additives and soils. The common chemical reactions normally include cementation, hydration, ion exchange, flocculation, precipitation polymerisation, oxidation and carbonation (Fang, 1990). The chemical stabilisation in which the cementation is the major or one of the major chemical reactions could be a cheapest and easiest method in engineering practice.

There are numerous chemicals or chemical stabilising agents used for various soil stabilisation purposes. The most widely used agents are cement, the modified cementitious chemicals, lime, bitumen, resin, the wastes like Fly-ash from power plants and others such as salts and acids. The selection and application of stabilising agents may be subject to constraints with respect to local conditions such as economy, environment, soil conditions and engineering experience. Some of commonly used stabilising agents for road construction will be discussed later in this paper.

There are two major construction methods of the chemical stabilisation for roads. One is the insitu mixing/recycling way and another is the central plant mixing way.

2.1 Insitu Mixing/Recycling

The construction procedure of this method normally includes three main steps:

- ❑ spreading (of the chemical agent on the soil layer to be stabilised);
- ❑ mixing (the agent with soils to be stabilised); and
- ❑ compaction (of the mixture).

With the different construction machines, the insitu mixing methods can be classified into two ways:

Simple Way: It includes Manual Spreading, Mixing with Simple Machines (such as Rotorvator or other agricultural mixing machines) and compaction (Photo 1).

With this simple way, the stabilised depth is only up to about 200mm and the construction speed is lower. The mixing efficiency and quality are lower, and a higher dosage of the stabilising agent is required. Currently this way is still widely used for small or rural roads in this region such as in Malaysia and Indonesia.

In 1950s, it is the only available way for chemical stabilisation works in Brunei.

Advanced Way: A mechanical spreading is done by the Spreader specially made with or without computer control, an advanced self-running mixer called Stabiliser or Recycler be used for the mixing, and the compaction is conducted by rollers with higher capacity (Photo 1).

The advanced way is much better the simple way almost in all respects. The stabilised depth could be up to 400mm or more and the mixing quality is close that handy mixing in laboratory. The higher construction speed is another advantage, where a construction speed of 7,000 to 8,000m^2 per day is achievable according to the record of Chemilink soil stabilisation for a new shipyard in Indonesia.

Only this method has been used in Brunei since 1995.

Mechanical Spreading | Mixing by Stabilizer | Compaction 1

a. Advanced Way

Manual Spreading | Mixing by Rotovator | Compaction 2

b. Simple Way

Photo. 1: Insitu Mixing Method

2.2 Central Plant Mixing

The materials to be stabilised are mixed together with the agents in the central mixing plant and then the well-mixed mixture is transported to the site for laying and compaction. By using this method, the mixing quality and efficiency are very good and it also enables the construction speed much higher and potential. The available capacity of the compaction machinery often controls the thickness of the stabilised layer. The transportation distance, transported volume and the chemical setting time may affect the construction speed, quality of the mixture and the cost too. Furthermore it will have a double-handling issue if recycling the insitu soils. If the application conditions are not suitable, this method may be costly and its impact to public traffic could be significant. For the information, a local contractor may try this method for some portion of a newly awarded road project soon.

3. MAJOR PROJECTS WITH CHEMICAL STABILIZATION IN BRUNEI

Since 1995 the chemical stabilisation has gradually been applied and currently it has become a popular and conventional method for public road construction. The major site trials and road projects with the chemical stabilisation in Brunei (1995-2002) has been summarised in Table 1.

Table 1
List of Major Trials/Projects with Chemical Stabilisation (1995-2002)

No	Project Name	Base	Sub-base	Project Value (B$)	Compl. Year/ Status	Remarks/ Main-Con
1	1st Trial of Chemical Stabilisation at Jalan Rambai	a) CR + Cement b) CR + Polyroad c) Silty soil +	a) Existing b) Existing c) Clayey soil + SS-108 (200mm)	–	1995	Surati
2	Rehabilitation of Jalan Junjungan, Using "Cold Deep In-Place Recycling Process"	CR + Cement (200 mm)	Soils + SS-108 (225 mm)	18.9M	1998	Surati
3	Widening of Jalan Tutong KM 6-13, Phase II	CR + Cement	Soils + SS-108 (300mm)		1998	Ocean
4	Road Construction with Different Designs Using Chemilink Technology for Brunei Road Specification	a) CR + Cement (200 mm) b) CR + Cement (200 mm)	a) Soils + SS-108 (225 mm) b) Compacted sands		1998	Surati
5	Rehabilitation of Jalan Mulaut - Limau Manis Sengkurong to Kuala Lurah Junction	CR + Cement (200 mm)	Soils + SS-108 (225 mm)		1998-2000	LEC
6	Jalan Tutong Widening from Jalan Tutong to Gadong Junction, Phase III	CR + Polyroad (220 mm)	Silty Soils + SS-108 (350 mm)	66.5M	1998-2000	Surati
7	Rehabilitation of Jalan Mulaut - Limau Manis, Phase II	CR + Cement (200 mm)	Soils + SS-108 (250 mm)		2000-2001	Surati
8	Road Maintenance of Jalan Tutong, Phase I	CR + SS-111	Existing	–	2000	A trial on a section/ Swee
9	Tanah Jambu Link Road	CR + Cement	Soils + SS-108		2001	Dara J-V
10	Improvement of Roads within Istana Nurul Iman Compound	CR + SS-111	Existing		2002	Swee
11	Full Scale Trial Pavement for Chemical Stabilisation on Soft Ground at Mukim Sengkurong and Kilanas	a) CR + SS-108 b) CR + SS-111 c) CR + Cement + Renolith	Existing		2002/ On-going	Surati
12	Re-Construction of Jalan Lamunin-Rambai-Merimbun Tutong District	CR + SS-111	Soils + SS-108	13.0M	2002-2004/ On-going	Pahaytc

1) CR: Crusher Run
2) SS-108: Chemilink SS-108 Soil Stabilisation Agent
3) SS-111: Chemilink SS-111 Stone Stabilisation Agent

4. PROJECT PERFORMANCE AND BENEFITS BY USING STABILIZATION

Several typical projects of chemical stabilisation are selected and introduced here due to the limit length of the paper. Furthermore their performances and benefits by using chemical stabilisation have also been presented and discussed as follows.

4.1 First Trial Project

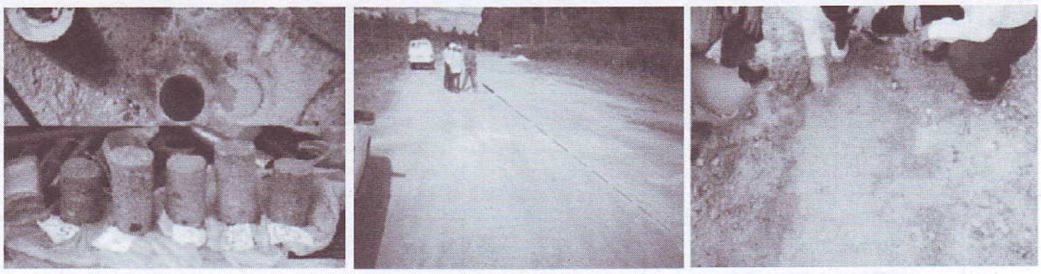
The first trial of chemical stabilisation with Cement, Polyroad and Chemilink SS-108 was carry out in 1995. Cement and Polyroad as the base course stabilised the crusher runs layers. The Chemilink SS-108 soil stabilisation for the sub-base and base courses is situated at a widened section of swampy and low-rural road in Tutong District (Yong and Wu 1999). The CBR value of the insitu soils before Chemilink stabilisation is less than 2%. The insitu sandy clay was stabilised with 3% (by dry weight of the soil) of Chemilink SS-108 Soil Stabilising Agent to form a 200 mm thick sub-base course. In order to increase the elevation of the road surface, the surrounding sandy silt was backfilled on the stabilised sub-base course. The backfilled silty soils with a thickness of 200 mm was stabilised by Chemilink SS-108 as the base course. The average insitu CBR value after four soaking/wet days is about 100%. For monitoring the performance and behaviour of the stabilised pavement, no asphalt concrete surface layer was applied and the base course functioning as a road surface was opened to public traffic.

Four months later the insitu and laboratory tests were conducted and a set of testing data is given in Table 2 (Yong and Wu 1999). Some stabilised samples are shown in Photo 2-a.

Table 2
Average Testing Data for Chemilink Trial Project

M/P Test		Plate Loading Test			Insitu CBR Test (%)	UCS Test (MPa)
No. of Blows	Depth of Penetration (mm)	Peak Pressure (MPa)	Settlement Recorded (mm)	Modulus Of S/R, K (MPa)		
300	6.3	1.72	7.44	522.62 (Max. 812.48)	100 (Max. 129)	2.04 (Max. 2.67)

1) M/P Test: Dynamic Mackintosh Probe Test
2) Modulus of S/R: The Modulus of Sub-grade Reaction
3) UCS Test: Unconfined Compressive Strength Test



a) Stabilised Samples b) Stabilised Road (on the left) v. old road after many years c) Stabilised Surface

Photo 2: The 1st Chemilink Trial Project

From the completion of this trial, the following-up site visit was conducted at least once a year. Based on the site observations for past 7 years, the conclusions on the performances of chemical stabilisation look very encouraging and attractive. The structure of the stabilised pavement is still sound even after 7 years. Comparing with the multi-ten years old road on one side, neither significant total settlements nor obvious differential settlements can be observed (Photo 2-b) for the new stabilised road on another side. And the stabilised surface is solid and has no cracks after so many years (Photo 2-c).

4.2 Junjungan Project

This was the first rehabilitation project using insitu chemical stabilisation and pavement recycling method in Brunei (Yong & Hussien, 2001). This road was constructed in the early 1970s, which is sitting on the low and swampy land with the poor sub-soils including peat and organic clay, and with high water table during the rainy season. During the past about 30 years, the pavement was deteriorating rapidly and certain sections were prone to

flooding due to the settlements caused by the poor sub-soils. In addition to rehabilitation of the 6m wide existing pavement with the cement stabilised basecourse and new asphalt concrete, the road was widen to one side with 5 m width, where 3 m is carriageway and 2 m is the paved road shoulder.

The key challenge in design and construction of this road is how to prevent differential settlements between the existing pavement and the widening portion sitting on a fresh foundation with peaty sub-soils. In the widening portion, the sandy silt with 1.5 m thick was backfilled and 2.5% of Chemilink SS-108 was used to stabilise the top layer (250 mm) of the backfilled sandy silt. Furthermore 4.0% of cement was used to stabilise the crusher run stone base layer with 350mm thick. According to the report (Yong and Hussien 2001), the designed parameters are CBR >30% and UCS (7 days) >1.0 MPa for Chemilink stabilised sub-base and UCS (7 days) >4.0 MPa for cement stabilised base respectively, where CBR is California Bearing Ratio and UCS is Unconfined Compressive Strength.

The costs of the chemical stabilisation with cement and Chemilink SS-108 have been analysed in details and compared with those of conventional methods (Yong and Hussien 2001). The conclusions were that the cost of Chemilink stabilised sub-base was almost equivalent to that of the conventional unbound sub-base and that the cost of cement stabilised base was much lower than that of conventional method if the existing stones can be recycled. However the benefits and advantages derived from the chemical stabilised soils/stones are far more superior to those of conventional methods, which will be discussed later in this paper.

The project was started in December and completed in June 1998. The road has been opened to the public with excellent running conditions for more than 4 years and no major defects or pavement failure been detected (Photo 3). It is very interesting to notice that though there are a lot of surface cracks along the cement stabilisation construction joints that are about 1m away from the boundary between the both new and old pavement; there are no any signs to indicate the differential settlements between the new pavement and old one. Furthermore the total settlement of the new road looks quite limited.

Photo 3: Junjungan Road (after more than 4 years)

4.3 Widening of Jalan Tutong, Phase II

This is a project located at a poor sub-soils foundation connecting to the road of the same project of Phase I, where the environment and soils conditions for both project at different phases are very similar. The original pavement design is the same as that of the Phase I. In the design, 2 m thick of sandy soils was backfilled to replace the weak soils of the existing sub-grade. The sub-base and base courses were constructed with three layers of a Geogrid system with 300 mm thick of local crusher rock and with a layer of 250 mm thick imported crusher run stone. 100 mm of asphalt concrete in 2 layers was finally laid as the binding and wearing courses. However within a relative short time from the completion of the Project - Phase I, a lot of differential settlements gradually occurred and became more significant. The functions of the geogrid system were suspected.

A modified pavement design for the Phase II was thus proposed after this project was started. In the modified design, the geogrid system was removed and the chemical

stabilisation was introduced, where the top layer (300mm) of the sub-grade was stabilised by 2.5% of Chemilink SS-108 and the 300mm thick sub-base was stabilised by cement. A layer of 150 mm thick imported crusher run stone was proposed to be the base course and the anti-cracking function from the cement stabilisation is an additional advantage of this base layer. 100mm thick asphalt concrete was designed as the road surface. The cost of the modified design is cheaper than that the original design.

The road using chemical stabilisation has been opened to the public since 1998 and no any major defects and failures are found so far (Photo 4). Comparing with the performances of the Project - Phase I with the geogrid system, there are no observable differential settlements occurring in the Project - Phase II constructed with chemical stabilisation.

Photo. 4: Jalan Tutong Widening, Phase II (4 years later)

4.4 Jalan Tutong Widening, Phase III

This is one of the biggest road projects in Brunei with a project turnover of B$66.5 millions. Comparing with the previous widening projects, Phase I and Phase II, the soil conditions are worse and the water table is higher. In the original design proposal, the sub-base contained a layer of geotextile and a layer of 225 mm thick crusher rock. A layer of 170 mm thick dense bitumen macadam formed the base course. The surface was 100mm asphalt concrete. Furthermore in the original design a lot of efforts had been contributed to the improvement of the sub-grade. As least 1m thick backfills including 300 mm thick crusher run with a geogrid system on the top of pilling foundation. The similar design system was applied in another road project several years ago from the time that the original was proposed and its performances were not very satisfactory. Furthermore the cost by using this system with the pilling foundation all over the road is too high to accept.

Further intensive technical studies and discussions were conducted and a comprehensive design was finally concluded. For the road pavement, the sub-base included a lower layer of 100mm thick well-compacted sandy fill with a layer of geotextile on the bottom and a layer of 350 mm thick sandy soils stabilised by 2.5% of Chemilink SS-108. A 220 mm thick crusher run stabilised by 1.5% of Polyroad, where Polyroad has a good water resistant but has limited binding effect, formed the base. The design of the surface layer remained the same. For the improvement of the sub-grade, only about 30% of the pilling foundation was used for those important areas such as road junctions and the places where no settlements are allowed. To link the bearing-piling areas to the none-pilling areas, a transaction piling system was introduced in order to form a smooth surface slope corresponding to the gradually changed settlements.

During the construction, a lot of laboratory and insitu tests as well as site observations were conducted to ensure the installation qualities. The average results of UCS (unconfined compressive strength) tests, insitu CBR tests and degree of compaction tests, and some data of the modulus of sub-grade reaction from the insitu plate loading tests are given in Tables 3 and 4 respectively for both chemical stabilised sub-base and base courses. Furthermore several cross sections were cut and opened in order to directly observe and check the quality and performance of the chemical stabilised layers (Photo 4-a). Based on these testing results and direct observations, the stabilised layers were solid and had no deformation.

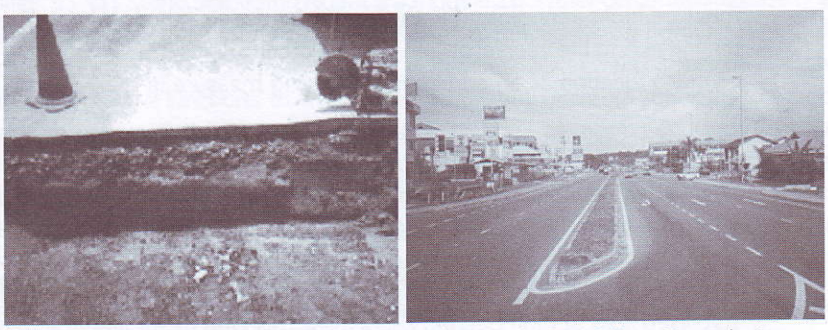
Table 3
Average Testing Results for Jalan Tutong Widening, Phase III

Products	Sample No.	UCS Test(MPa)		Insitu CBR Test (%)	DOC Test (%)	Remarks
		4-day soaked	unsoaked			
2.5% Chemilink SS-108 with sandy soils	129~163	1.3	1.62	81.25	> 97	sub-base
1.5% Polyroad with crasher run	63~121	1.19	1.52	184.26	> 99	base

1. The samples used for UCS tests were made in Lab using the mixtures from site.
2. In-site CBR tests were normally conducted after 2-4 curing days.
3. DOC means the Degree of Compaction.

Table 4
Plate Loading Test Data for Jalan Tutong Widening, Phase III

Products	Location-1 CH 2870~71 K (MPa/m)	Location-2 CH 2960~61 K (MPa/m)	Location-3 CH 3391 K (MPa/m)	Average Modulus of Subgrade Reaction K, (MPa/m)
2.5% Chemilink SS-108 with sandy soils	895	564	894	784
1.5% Polyroad with crusher run	501	623	508	544



a) Opened Road Cross Section b) Road after 2-Year Completion

Photo. 5: Jalan Tutong Widening, Phase III

The road has partially or completely been opened for public traffic for about 2 to 3 years and there are no any signs of major defects and structural failures. Because of using chemical stabilisation design, the immediate cost saving is very significant. A further cost saving in maintenance is expected based on the experience from other chemical stabilisation projects.

5. CHEMICAL STABILIZING AGENTS

There are numerous chemical stabilising agents for the construction of roads and various other shallow base foundations. Cement stabilisation is the most common method while lime stabilisation is the oldest known method of chemical stabilisation in the world. However the stabilisation's with modified cementitious or polymer bases chemical stabilising agents, are sometimes more technically and commercially effective and durable.

It should be emphasised that any good stabilising agent must be able to overcome the both general engineering difficulties and localised construction troubles. The universal stabilising agents do not exist. There are some specific difficult conditions for road construction in this region especially in Brunei, such as rainy weather conditions, low-lying land, high water table, swampy areas, wet soils and poor or trouble soils. More attentions and efforts have to be paid to these localised difficulties.

5.1 Cement

Various types of cement have been used for the purpose of soil stabilisation and the Portland cement, which is the finely powdered hydraulic cement, could be most widely used cement among the cement family. For granular soils, cement can increase strengths of the stabilised soils and decrease the permeability mainly through cementation. Practically, the cement stabilisation is effective for most of granular soils but ineffective for cohesive soils because of high dosage, difficulties in construction especially when the soil is wet, and excessive shrinkage properties. Ideal application of cement stabilisation is applied with a well-graded soil containing gravel, coarse sand and fine sand with or without small amounts of silt or clay.

Cement stabilisation may be a cheapest and simplest method among the chemical stabilisation. There are sufficient experience and established technical data for cement stabilisation in the world. The major disadvantages of this method are the application range limiting to the contain types of soils and the shrinkage cracking. The wet soils will also cause difficulties during the mixing and compaction.

5.2 Lime

It is another commonly used additive for soil stabilisation or for improving soil properties. Lime stabilisation is suitable to the clayey soils with advantages like reducing the plasticity index, decreasing the clay content substantially, accelerating the breaking up of clay clods during mixing, drying out the water from wet soils, reducing the shrinkage and swelling, and increasing strengths of the stabilised soils after curing. The increasing process and the increment of strengths of lime-soil are much lower by comparing with those of cement stabilisation. The more important disadvantage is the durability of lime stabilisation in this tropic region.

Thus the lime stabilisation can independently be used for sub-grade and sub-base or other pavement layers with lower bearing capacity requirements. It is frequently used as a preparative measure for subsequent treatment with other chemical stabilisation, where this measure looks very difficult in this region because of the local conditions such as frequent raining during the interval of lime and the other chemical stabilisation's. The lime stabilisation can also function as an additional improving measure in granular soil stabilisation.

5.3 Other Agents

Bituminous stabilisation with bituminous materials (organic type of materials) such as Bitumen incorporated with soils or soil-aggregate mixture can be used to construct base courses, sometimes to form surface courses. The key function of bitumen is to waterproof soils to be stabilised as a mean of maintaining them at low moisture contents and thus remaining the stabilised soils at high bearing capacities. This type of stabilisation may be affected by the cost and environment requirements.

Fly-ash is a by-product of power plants fuelled by pulverised coal. About 70% of its chemical composition is alumina and silica. It reacts with Lime in the presence of water, setting and hardening similarly to hydraulic binder (Fang, 1990). Fly-ash is often used with Lime to stabilise the soils. Furthermore the soil stabilisation with several stabilising agents of Cement, Lime and Fly-ash has been proven to be effective and economical in many countries, especially for highway construction in China. For passed multi-ten years, the combination of chemical stabilisation's with two or more different stabilising agents has shown superior effectiveness and wider applicable range, if comparing with the soil stabilisation only with one stabilising agent.

As discussed above, the conventional stabilising agents such as Cement, Lime, Fly-ash and Bitumen have their advantages, disadvantages and limits of application. Especially and specifically for local conditions in Brunei, the modified and/or combined chemical stabilising agents are required in order to effectively overcome the local difficulties.

Some stabilising agents in liquid form with various chemical-bases have been tried in Brunei for passed years and the results are not satisfactory. Chemilink Stabilising Products are the only type of chemicals in powder form that were tested in Brunei and their effectiveness and durability especially for Chemilink SS-108 soil stabilisation have been proven and presented in Brunei public roads for passed about 7 years.

5.4 Chemilink Stabilising Agents

In order to effectively overcome the construction difficulties in this tropic region and to enlarge the application ranges of chemical stabilisation, Chemilink SS-108 Soil Stabilising Agent and Chemilink SS-111 Stone Stabilising Agent were especially invented and developed. The products have been tried, verified and applied in South East Countries and China Since 1994.

Chemilink SS-108 is a modified cementitious chemical agent in fine powder form and designed for soil stabilisation especially for sandy and silty soils under tropical conditions and environment. The basic functions of Chemilink Stabilising Agents can be summarised as follows:

- To improve and maintain the soaking strengths of soils and thereby improve the bearing capacity of sub-grade or stabilised soils through binding particles of soils and immediate chemical reaction with soils.
- To form a semi-solid platform with a certain tensile strength and thereby reduce total settlements and minimise differential settlements.
- To decrease the compressibility and permeability of the stabilised soils and to provide anti-cracking effect, and thereby to reduce or eliminate the potential damages due to swelling, shrinkage and seepage.
- To improve the long-term performance of soils.

From these basic functions, the advantages and the resulted benefits by using Chemilink Stabilisation have been drawn and presented by Yong and Wu (1999).

In addition to the basic functions as mentioned above, Chemilink SS-108 Soil Stabilising Sub-Series Products have some special functions, such as quick chemical reaction for increasing the initial strengths of soil-chemical mixture; breaking up of clay clods during the mixing for enlarging their application range to soils; quickly drying out the water from wet soils for better compaction of wet soils and pre-expansion for preventing the shrinkage cracking.

Chemilink SS-111 Stone Stabilising Agent is a modified polymer-cementitious base chemical in powder form for chemical stabilisation of crusher run stones and gravel. With the most of technical functions of Chemilink SS-108, Chemilink SS-111 was specially designed to have three additional functions: to improve the flexibility, to increase strengths to a moderate level and to have anti-shrinkage cracking capacity. The polymer compounds inside of the chemical not only improve the elastic property substantially but also prevent the water in the mixture from losing. It is expected that the resilient modulus of the road base stabilised by SS-111 is lower than or equivalent to that of road surface layer of asphalt concrete.

Conventionally, one of the key dosage design criteria of stabilised soils is the achieved compressive strength in terms of CBR value and/or the unconfined compressive strength (UCS). Normally for fine-grained soils, both CBR and UCS are used and CBR is more frequently used, while for coarse-grained soils CBR testing data may not be accurate or correct. In this region, a simple and conventional principle, that CBR is not less than 30% for sub-base courses and 80% to 90% for base courses, is often applied for soil stabilisation. According to the relevant highway specifications in some countries that are experienced in chemical stabilisation, the UCS values of 1 to 2 MPa for sub-base courses and 3 to 4 MPa for base courses are commonly applied. For normal roads, the smaller values should be selected. The resilient modulus of the stabilised materials is another important design parameter especially for the road base. It is also a comprehensive testing data related to the strengths, rigidity, and capacities of dynamic rebound.

In Brunei specification for stabilisation (CPRU 1999), the requirements of soil stabilisation for the sub-grade (or sub-base) are that the CBR value is not less than 30% and the UCS value is 0.7 to 2.5 MPa. Furthermore, in this specification, the requirements on the resilient modulus for base courses stabilised by different chemicals are specified, where for example, the resilient modulus for the base stabilised by cement and bitumen is required not lower than 5,000 MPa.

It should be noted that the over-design in chemical dosage of stabilising agent will commercially cause cost ineffective and could technically cause the reversed effects. For examples, if the dosage of Cement is too high (e.g. more than 6% to 10%) in normal conditions, more and more shrinkage cracks will occur over a quite long period, while the

higher usage of Chemilink SS-111 in gravel stabilisation may cause the pre-expansion too high so that the gravel may have a going-up effect because the compressibility of the well-compacted gravel is lower. Furthermore more attentions should be paid on the issues caused by the construction joints of chemical stabilisation.

Currently Brunei PWD is carrying out a further comprehensive study on chemical stabilisation on soft ground (refer to Project No. 11, Table 1). Chemilink SS-108, Chemilink SS-111 and Cement with Renolith have respectively been used as the chemical stabilising agents to stabilise the local crushed stone for the road bases with different designs. The main purpose is to identify more and better solutions under local conditions for more quality roads through observing and investigating the behaviours and long-term performances of these chemical stabilisation's and also through obtaining or accumulating more technical data for further development and improvement in local chemical stabilisation works.

6. QUALITY CONTROL

A proper and practical quality control of chemical stabilisation is very necessary and sometime vital to comply with the design requirements and to achieve the targeted results. It can also set up a common guideline for consultants and contractors to assure construction qualities before, during and after stabilisation process.

Based on the established international practice and local engineering experience, an authorised specification called "General Specification for Pavement Stabilisation" was published by Brunei PWD in 1999 (CPRU, 1999). In the published specification, the detailed regulations and requirements on quality assurance and quality control for the chemical stabilisation's with Cement, Cement/Bitumen, and Polymer-base and cement-base products have been specified for road pavement construction. The quality control requirements with testing methods, targets and tolerances, minimum checking frequencies and recording manners for each type of chemical stabilisation's have mainly included the following aspects and elements:

- Preparations that require the determinations of the properties of the insitu or imported materials to be stabilised; and of the chemical stabilising agents to be used.
- Construction that requires the inspections of spreading quality with the mechanical spreader; mixing depths and widths; overlapping widths and lengths; timing limits from mixing to compaction; moisture controls; and compaction controls.
- Finishing that includes level controls; surface finishing tolerances; and curing process.
- Results that provide the testing requirements during and after construction in order to determine the relevant strengths; resilient modulus and other necessary technical data.

The quality control requirements for chemical stabilisation of sub-grade in the specification (CPRU, 1999) are selected and illustrated in Table 5 as an example. Furthermore some requirements of quality assurance are also recommended (Instek 1995), which is to ensure soil stabilisation under qualified site personnel and with proper construction machinery.

Table 5
Quality Control Requirements for Chemical Stabilisation of Sub-Grade

Element	Test Method	Target	Minimum Frequency	Record
Suitability of using existing material	CBR tests to BS 1377	5%	as required with change in soil conditions	Test Report
Depth of stabilisation	Measurement	1.4 times designated thickness	every 50 meters	Daily Report
Dosage and spreading	Weighing and visual inspection	Not less than specified value	every 40 meters	Daily Report
Overlapping - Minimum Lengths	Measurement	Long : 0.3m Lateral : 1.0m	every 50 meters	Daily Report
Resultant strength	CBR and 28-Day UCS tests according to BS 1377	> 30% and 0.7-2.5 MPa	every 50 meters or a determined by RE	Test Report

7. CONCLUSIONS

- Road construction with the chemical stabilisation method was initially applied in Brunei in 1950s. Since 1995, the chemical stabilisation has been tried and then popularly been used for Brunei public roads. Chemical stabilisation with proper stabilising agents and with advanced construction machinery could be one of the best satisfactory road construction methods under local conditions in Brunei.
- More than ten road projects with chemical stabilisation method have been carried out and the performances of the completed roads are generally satisfactory. With chemical stabilisation method, many technical difficulties, especially the total and differential settlements, at swampy or low-lying land areas with peaty soils have successfully been resolved. The benefits and advantages derived from chemical stabilised roads are far more superior to those of roads constructed by conventional methods.
- Chemilink SS-108 Soil Stabilisation has been proven to be the technical and cost effective and durable method for road construction, based on the performance and durability of many local public roads with Chemilink(Technologies and Products.
- The commonly used chemical stabilising agents are reviewed and discussed in the paper. The major criterion of selecting the agents has been proposed that the right agent must be able to overcome the both general engineering difficulties and localised construction troubles. It is recommended to pay more attention on the modified cementitious base and/or polymer base stabilising agents because of the effectiveness and durability.
- Brunei PWD has published the General Specification for Pavement Stabilisation for chemical stabilisation practice since 3 years ago and the guidelines of quality control has been provided in the specification. It is necessary and vital to comply with these quality control requirements in order to achieve successful stabilisation works.
- Further studies and improvements of chemical stabilisation will continuously be carried out in order to develop and introduce advanced stabilisation technologies and materials for more and better quality roads in Brunei Darussalam.

REFERENCES

Fang, H.Y. (1990). Foundation Engineering Handbook, 2nd Edition, New York, USA.

Instek Holding Pte Ltd (1995). Quality Control Guideline for Chemilink(Application on Roads. 1st Edition, Singapore.

Myles, G.T. Soil Cement Stabilized Roads in Brunei, Borneo", Brunei PWD Report No. 83901. 1950s.

Yong, T.C. and Wu, D.Q. (1999). Chemical Stabilization for Road Construction in Brunei Darussalam. Proc. First International Conference on Transportation for Developing Countries on Threshold of the 21st Century, Nov. 18-19, Hanoi, Vietnam, pp. I.26-I.32.

Yong, T.C. and Hussien, R. (2001), Rehabilitation of Jalan Junjungan by Using Insitu Stabilization and Recycling Method. Proc. 19th Conference of Asean Federation of Engineering Organisations, Brunei Darussalam.

ACKNOWLEDGMENTS

The paper was presented at "The Regional Seminar on Quality Roads - The Way Forward", October 2-4, 2002, Bandar Seri Begawan, Brunei Darussalam.